Optimisation Processing of Green Kiwifruit-Blackcurrant Leather Using Response Surface Methodology

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Abstract

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The purpose of this study was to efficiently produce a green kiwifruit-blackcurrant fruit leather with acceptable colour and taste characteristics. The effects of different levels of sugar, blackcurrant purée and green kiwi fruit purée and a small addition of pectin were analysed using response surface methodology to identify a range of optimal ingredient levels.

An advanced software programme, Design-Expert which used a Box-Behnken method was used to design the experiment. Sixteen different combinations suggested by the programme were investigated, using constant drying conditions, to determine the final moisture contents, water activity, colour, texture and ascorbic acid contents of the green kiwifruit-blackcurrant fruit leather produced. The outputs of the data-derived analysis from this programme were then analysed using multiple regression and ANOVA analysis was used to identify the significance of the developed models. The data were then plotted using three dimensional surface plots so that the interaction of the different parameters could be observed.

This analysis showed that the optimum combination for the manufacture of kiwifruit-blackcurrant fruit leather was 81.02% kiwifruit purée, 8.95% blackcurrant purée, 10% sugar and 0.03% pectin.

Central composite analysis was then used to investigate the effect of drying conditions; temperature, time and sample thickness on this optimum ingredient combination. Eighteen different combinations of drying time, temperature and sample thickness suggested by the programme were then applied to the optimised fruit leather mixture and the outcomes analysed for final moisture contents, water activity, colour, texture and ascorbic acid contents of this green kiwifruit-blackcurrant fruit leather dried at each set of conditions.

The data were then plotted using three dimensional surface plots so that the interaction of the three drying parameters could be observed. The optimum drying conditions for a product with the highest desirability as defined by the programme, were 14.73 hours of drying time at 67.32°C with a sample

thickness of 8.00 mm. Under these conditions the predicted responses were moisture content of 33.72 g/100 g DM; water activity, 0.67; L*, 28.25; a*, 6.89; b*, 1.08; chroma, 6.57; puncturing force, 0.19 N/mm and ascorbic acid content 164.51 mg/100 g DM.

Sensory analysis showed that the optimised recipe was appreciated by almost all panellists and this was confirmed by their overall liking score for this recipe. The flavour and colour of the fruit leather were the most important characteristics appreciated by panellists. The very dark colour of fruit leather made from blackcurrant alone was the most disliked feature. The optimised recipe derived from the data generated by response surface methodology using a mixture of kiwifruit and blackcurrant purée and processed using optimum conditions produced the most acceptable colour and texture and received the highest overall liking score. The textural property, which was critical for customer acceptance in the taste test was determined by measuring the force needed to puncture the fruit leather. The puncturing force of fruit leather increased with increasing pectin content, increasing drying temperature and decreasing sample thickness.

Overall, the fruit leather made from a combination of kiwifruit and blackcurrant purées using the most efficient combination of materials and processing conditions was identified by response surface methodology methods. The optimised fruit leather was soft and tasty and had the highest overall liking of all the fruit leathers tested in a sensory evaluation experiment.

Keywords: Green kiwifruit, blackcurrant, fruit leather, processing, optimisation, response surface methodology, sensory evaluation.

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Chapter 1
Introduction

Fresh fruit, such as green kiwifruit (*Actinidia deliciosa* 'Hayward') and blackcurrant (*Ribes nigrum L.*, *Grossulariceae)* have short harvest seasons and are unstable even when stored under refrigerated conditions; therefore, making these fruits into fruit leathers is a way to preserve the fruit and retain important nutrients such as vitamin C, polyphenols and anthocyanins. These nutrients are becoming important selling points for both fresh and processed foods. There are a number of papers which describe making fruit leathers from a single fruit (Chan and Cavaletto, 1978; Irwandi *et al*., 1998; Vijayanand *et al*., 2000; Maskan *et al*., 2002; Gujral and Brar, 2003; Huang and Hsieh, 2005; Jaturonglumlert and Kiatsiriroat, 2010; Vatthanakul *et al*., 2010; Chowdhury *et al*., 2011; Demarchi *et al*., 2013; Sharma *et al*., 2013). Only a few authors (Bains *et al*., 1989; Kumar *et al*., 2010; Diamante *et al*., 2013a) have used two different fruits to make a composite fruit leather. Combining two fruits in one fruit leather product combines the advantages of the individual fruits. In addition, the strong purple reddish colour of the blackcurrants will dominate the colour of the fruit leather since the green colour of kiwifruit tends to be lost during drying.

Fruit leather, also called a fruit bar or a fruit slab, is a dehydrated, fruit-based, confectionery, dietary product that is often eaten as a sweet, cooked as a sauce or used as an ingredient in beverages (Ashaye *et al.*, 2005; Raab and Oehler, 1999). Because fruit leathers are made from natural fruits they often contain fewer calories than many other snacks and are often considered to be a healthy snack (Phimpharian *et al.*, 2011).

The important properties of mixed fruit leathers include moisture content, water activity, colour, texture and vitamins (Diamante *et al*., 2013a). Both moisture content and water activity are the main factors which affect the shelf-life and food safety of fruit leathers (Fontana, 2008; Tapia *et al.,* 2012). Fruit leathers are easy to pack and store because of their low moisture content (Huang and Hsieh, 2005). The colour and texture of fruit leathers are also important factors which can influence consumers when they purchase the product. A dried product containing a significant amount of ascorbic acid makes the product more nutritious.

The properties of kiwifruit-blackcurrant fruit leather can be affected by a great many factors, such as the different levels of sugar, blackcurrant purée and pectin used to make the product. In addition, different drying conditions (including temperature, time and sample thickness) can also have a large influence on the final properties of the fruit leather. For example, adding sugar would give a sweet taste to the dried product and reduce the sourness of the product. The addition of blackcurrant purée to the fruit leather would also enhance the colour and nutritional characteristics of the dried final product. Moreover, the pectin would enhance the physicochemical and sensory qualities of the fruit leathers. Drying time and temperature and sample thickness will also affect the colour and nutrients of the fruit leather.

The successful manufacture of fruit leather involves changing the proportions of the fruit added, sugar and pectin, to achieve an efficient production of a product that has a good appearance and taste characteristics. In addition, temperature, time and thickness of the product can have a considerable effect on the quality of the final product. Investigating the effect of changing each parameter in turn to determine its effect on the final product is a very laborious and expensive process. Response surface methodology (RSM) is a relatively new statistical method that can be used to reduce the number of experiments that have to be carried out to understand the interactions between all the factors. The results from RSM analysis can identify the optimum processing conditions.

Earlier experiments have shown that the measurement of moisture (Perera, 2005) and water activity (Fontana, 2008) are important in determining the stability and shelf-life of the dried product (Azeredo *et al.*, 2006). Measurement of the puncturing force (Huang and Hsieh, 2005) gives information about the texture of the product while measurement of the CIE colour values gives some data on its visual appeal (Clydesdale, 1993). Determination of the vitamin C content of the dried product gives an indication of the heat processing of the product and is useful data to promote the healthy characteristics of the dried fruit product (Diamante and Yamaguchi, 2012; Diamante *et al.*, 2013a).

Chemical analysis of a food product can give information about its safety and potential shelf-life (Huang and Hsieh, 2005; Raab and Oehler, 1999; Phimpharian *et al.*, 2011; Gujral and Khanna, 2002) but it must be remembered that the ultimate test occurs when the product is eaten. Sensory evaluation combines an analysis of the colour, taste and texture, which are essential to the successful development of a new product (Stone and Sidel, 2010).

The objectives of this study were to make a green kiwifruit-blackcurrant fruit leather product efficiently. To achieve this goal, the present study would determine the effects of the levels of sugar, blackcurrant purée and pectin, and different drying conditions of temperature, time and sample thickness, on the final moisture content, water activity, colour, texture and ascorbic acid content of kiwifruit-blackcurrant fruit leather. The results obtained will be used to determine the optimised conditions for processing kiwifruit-blackcurrant fruit leather. Finally, five fruit leather products were evaluated using sensory analysis to measure the acceptability of kiwifruit-blackcurrant fruit leather.

Chapter 2
Literature Review

Drying food is one of the oldest methods of preserving food for later consumption. Fruit leather (sometimes called a fruit bar, a fruit slab or a fruit roll) has become popular in recent years. This product is made by drying fruit purée, or a mixture of fruit juice concentrates, with other ingredients such as sugar, pectin, fruit acid and colour on a flat surface in an oven, in a desiccator, or in direct sunlight. It is a practical way to reduce the moisture content and, therefore, the possibility of microbial growth of the product. As the product has low moisture and high carbohydrate contents, its packaging requirements are simple and the product has a relatively long shelf-life (Ashaye *et al.*, 2005; Raab and Oehler, 1999).

Fruit leather is a confectionary or snack product and, because the water from the fruit has been removed, it has a sweeter and more intense fruit flavour. Almost any type of fruit can be used to make fruit leather. Fruit leather has been made from a number of single fruits but the idea of combining two different fruits to take advantage of each of their individual characteristics has not been fully explored.

Combining green kiwifruit (*Actinidia deliciosa* 'Hayward'), which are vibrant, green-fleshed fruits high in fibre with the tangy, sweet-sour taste of blackcurrants (*Ribes nigrum* L*.),* which have a very dark purple colour from the high anthocyanin content and a high ascorbic acid content offers an interesting combination of the characteristics of both fruits. These fruits are both readily available in New Zealand but the quality and acceptability of the final product using this combination has not been investigated. In common with other fruit leathers, the fruit sugar content of the two fruits needs to be supplemented with cane sugar and pectin to make a stable final product with a soft leathery texture.

2.1 Fruit leather processing

2.1.1 Single fruit leathers

There are a number of papers that describe making fruit leathers from a single fruit (Chan and Cavaletto, 1978; Irwandi *et al*., 1998; Vijayanand *et al*., 2000; Maskan *et al*., 2002; Gujral and Brar, 2003; Huang and Hsieh, 2005; Jaturonglumlert and Kiatsiriroat, 2010; Vatthanakul *et al*., 2010; Chowdhury *et al*., 2011; Demarchi *et al*., 2013; Sharma *et al*., 2013; Safdar *et al*., 2014; Valenzuela and Aguilera, 2015a; Valenzuela and Aguilera, 2015b).

Chan and Cavaletto (1978) investigated the effects of drying temperature, storage time, temperature of storage and sulphur dioxide on the quality of papaya leather. They found that the colour of the papaya leather was affected by the drying and storage temperatures. The presence of SO_2 could protect against darkening at high drying and storage temperatures. Their papaya purée was prepared by steaming whole papaya for one minute, slicing, and then separating the flesh, skin and seeds. They pulped the treated fruits and acidified them until the pH was 3.5. The purée was stored at −18°C after inactivating the enzymes by heating. Sugar and sodium bisulphite were added to the purées before they were dried in a forced temperature oven until they reached to 12 - 13% moisture content.

Irwandi *et al.* (1998) investigated the effect of the type of packaging materials with regards to the physicochemical, microbiological and sensory characteristics of durian fruit leather during storage. They processed durian leather from durian aril after blanching in a water bath at 85 – 100℃ for five minutes and then blending the cooked fruit with glucose syrup solid (GSS), hydrogenated palm oil, sucrose and soy-lecithin. The mixture was formed into 1.2 mm thick sheets and then placed in either an oven or in a cabinet dryer for dehydrating. It took 12.6 hours to dry at 50℃ in the oven and 10 hours at 52.5℃ in the cabinet dryer.

Vijayanand *et al*. (2000) uncovered the storage stability of guava leather prepared using a new process. The guava purée was prepared by washing ripe fruit, then crushing and extracting them using a pulper. A pectolytic enzyme, Rohapect D5 L, was added to the guava purée at 40°C. After two hours, guava juice was obtained by pressing the purées; this was then mixed with maltodextrin, sucrose, soluble starch, wheat flour, pectin, and potassium metabisulphite until it reached total soluble solids of 25° Brix. The mixture was then spread on stainless steel trays, which were smeared beforehand with glycerol, at the rate of 12 kg/m^2, and then dried at 50°C and 12% relative humidity (RH) in a cross-flow hot air dryer with a 2.5 m/s flow rate, to a final moisture content of 14 to 15%.

Maskan *et al*. (2002) investigated factors such as air temperature, sample thickness and air velocity in hot air drying and sun drying for the preparation of grape leather. The grapes were from Turkey. The grape purée was made by washing the grapes to remove dirt, leaves and foreign materials and then crushing and pressing them manually. Seven g of natural earth (70% $CaCO_3$) was added to the juice per litre to reduce the acidity and clarify the juice. The mixture was boiled for three to five minutes in order to inactivate the enzymes that cause colour changes. The foam formed on the surface of the juice during boiling was removed. The juice was then separated from the calcium tartrate precipitate by filtration and centrifugation to obtain the final clarified juice, which had a pH of 7.6 and 20º Brix. The total juice was then divided into two parts. A 3/4 part of juice was boiled again for 30 minutes with continued stirring to obtain a concentrated juice of 40° Brix. A wheat starch-juice mixture (starch dissolved in a 1/4 part of juice) was added to the boiling juice before boiling for another four minutes until it reached a concentration of 4 g/100 g of starch in the total fresh, clarified juice. The cooked grape juice-starch mixture was evenly spread on an 80 mm diameter disk of cloth and dried under hot air drying conditions or in direct sunlight. The concentrated grape juice mixtures were dried until there was no further weight change. For the sun-dried products, the samples were dried under direct sunlight for 14 hours.

Gujral and Brar (2003) studied the effect of hydrocolloids on the dehydration kinetics, colour and texture of mango fruit leather. The mango fruit were from India. The mango leather was made by passing the mango purée through a pulper to obtain total solids of 14.3%. The purée was then blanched at 80°C for 5 minutes and allowed to cool. Potassium metabisulphate (0.2% w/w) was added during cooling. Sugar (20%) was added to increase the sweetness and total soluble solids content. Hydrocolloids were also added to the mango pulp. The treated mango pulp was placed on aluminium trays measuring 2550 mm × 130 mm and 20 mm deep and dried in a cabinet dryer at 60 ± 1°C and with a relative humidity of 15%.

Huang and Hsieh (2005) investigated the physical properties, sensory attributes and consumer preferences of pear fruit leather. The pear juice was from the USA. They prepared pear leather with 18 different formulations, homogeneously blending pectin, water and corn syrup with different levels of pear juice concentrate. They mixed distilled water (23°C) into the pre-blended mixture of pear concentrate and corn syrup in a blender for one minute (both at 5°C), and then pectin was added to prevent the formation of lumps. They blended every second 400 g batch of the final mixture for another three minutes and then poured the treated batch into clean plastic flat-bottomed 70 × 100 mm containers. They left the containers on the bench at 23°C until the mixture became evenly distributed (approximately 1 minute). They made the final leathers by placing the containers in a convection oven at 70°C for eight hours, with an air velocity in 0.4 m/s.

Jaturonglumlert and Kiatsiriroat (2010) prepared longan leather by combining convective and far - infrared drying systems. The longan fruit were from Thailand. They made longan leather by uniformly spreading 100 g of longan purée in a tray and placing it in a drying chamber. The air velocity in the drying chamber was between 0 and 4.5 m/s and the temperature ranged from 30 to 80°C. A far-infrared ceramic heater with an intensity level control inside the chamber was used to heat the air. The sample for drying was kept in a tray under the IR heater. The sample for radiant heating was prepared by inserting a K-type thermocouple into the bottom of the purée layer. The combined convective and far-infrared drying experiment was organized at five temperatures with a distance between the sample and the infrared heat source of 100 - 300 mm. The inlet air temperature and velocity were maintained at 30°C and 0.5 m/s, respectively. The final moisture content of the sample was 14% DM.

Vatthanakul *et al*. (2010) investigated product development of gold kiwifruit leather using a quality function deployment approach. The gold kiwifruit fruit were from New Zealand. The basic ingredients of this fruit leather were pectin, sugar, salt, water, citric acid and glucose syrup. Nine formulations of fruit leather were produced using different combinations of pectin and glucose. Fruit purée and glucose syrup were mixed in a blender for two minutes before adding the other ingredients. The ingredients were mixed for an additional two minutes and immediately spread onto stainless steel drying trays when the blend was consistent. The trays were then covered with a polyethylene sheet to prevent the fruit leather from sticking to the trays during drying. They dried the gold kiwifruit leather using hot air at 70 ± 1°C for 12 hours in a batch tray dryer.

Demarchi *et al*. (2013) processed apple leathers at different temperatures. The apples were from Argentina. The apples were washed, cut into halves, cored, cut into 14 mm dices before steam-blanching them for 10 minutes to soften the tissues, to avoid enzymatic browning and to allow pectin to be dissolved and distributed before gelation occurred. Sucrose, citric acid, potassium metabisulphite, polydextrose powder and sucralose micronised powder were then added to the blanched apple purée. The apple purée mixtures were placed in 0.20 meters square stainless steel trays, with an initial thickness of 6 mm and dehydrated in a tray dryer at 50, 60, and 70°C, with an air velocity of 2 m/s.

Sharma *et al*. (2013) standardised a formula for the preparation of wild apricot fruit leather. The wild apricot fruits were from India. They washed the apricots and then heated them for five to seven minutes in a stainless steel pan with water before passing the fruits through a pulper to extract the purée. The purée was boiled over a low flame until its volume reduced to half and it was then mixed with different quantities of sugar. Weighed quantities of pectin (0.2, 0.3 and 0.4%) were sprinkled over the purée uniformly and mixed continuously mixing until smooth. The treated mixture was poured into aluminium trays (smeared with butter) in layers about 4 - 5 mm thick and the trays were then placed in a mechanical dehydrator at 55 ± 2°C for about six hours.

Safdar *et al*. (2014) investigated the nutritive and organoleptic characteristics of guava leather as influenced by storage period and packing materials. They washed the guava with distilled water to remove dirt, dust, pesticide residues and microflora from the surface of the fruits. The guava fruits were then weighed, peeled and cored. The flesh of each variety was cut into small pieces with stainless steel knives and a pulp was prepared using an electric blender. The guava pulp was pasteurised at 85℃ for 10 minutes in a pan placed in a water bath with 10% sugar and 0.1% potassium metabisulphite added. The pulp was then cooled and spread on polyethylene sheet in a 6 mm thick layer in the trays. Drying was carried out in hot air oven at 70℃ for 10 hours.

Valenzuela and Aguilera (2015a, b) investigated the effects of different factors on the stickiness of apple leathers and the effect of maltodextrin on the hygroscopicity and crispness of the apples. The apples were from Chile. They spread the apple purée as a thin layer in a 2 mm frame placed in an aluminium tray. The purée was levelled using a glass rod to ensure the thickness of the purée was uniform. The aluminium tray had previously been covered with a silicone sheet to prevent the apple leather from sticking to the tray during drying. The apple leathers were dried at 60 ± 1°C to a final moisture content of approximately 0.12 g water/g DM.

The additions and drying conditions, qualities and sensory data of single fruit leathers are shown in Table 2.1. Sugar and pectin were usually added to the fruit leather. Fruit leathers were usually dried at 50, 60 to 70℃ from 8 to 12 hours. 70℃ was most commonly used. The moisture content of final product were between 8 and 19%. Sensory evaluations (Chan and Cavaletto, 1978; Irwandi *et al*., 1998; Vijayanand *et al*., 2000; Huang and Hsieh, 2005; Vatthanakul *et al*., 2010; Sharma *et al*., 2013; Safdar *et al*., 2014) showed that panelists usually liked higher moisture, lighter colour and softer texture of fruit leathers.

Table 2.1 Summary of published research for fruit used and basic characteristics of fruit leather

References	Fruit	Additions	Drying conditions	Moisture and water activity	Sensory evaluation
Chan and Cavaletto (1978)	Papaya	Sugar and sodium bisulphite	74, 84, 94°C	12 - 13%	Lighter colour liked
Irwandi *et al*., (1998)	Durian	Glucose syrup solid	50°C, 12.6 h	15 - 16%, a_w 0.597	Higher moisture and lighter colour appreciated
Vijayanand *et al*., (2000)	Guava	Pectolytic enzyme	50°C, 12% RH	14 - 15%	Lighter colour soft texture appreciated
Maskan *et al*., (2002)	Grape		55, 65, 75°C sample thickness 0.71, 1.53, 2.20, 2.86 mm		No
Gujral and Brar, (2003)	Mango	Sugar, potassium metabisulphate,	60°C, 15% RH		No
Huang and Hsieh (2005)	Pear	Pectin, corn syrup, water	70°C 8 h	8.20 -13.47%, a_w 0.37 – 0.48;	Lighter colour softer texture appreciated
Jaturonglumlert and Kiatsiriroat (2010)	Longan		30 - 80°C		No
Vatthanakul *et al*., (2010)	Gold kiwifruit	Pectin, glucose	70°C for 12 h	8.06 – 11.25%,	Panelists liked higher moisture lighter colour
Demarchi *et al*., (2013)	Apples		50, 60 and 70℃		No
Sharma *et al*., (2013)	Wild apricot	Pectin (0.2, 0.3 and 0.4%)	55°C, 6 h 4 – 5 mm thickness	18.9%,	Panelists liked lower moisture content
Safdar *et al.,* (2014)	Guava		70°C, 10 h, 6 mm thickness	17.87%, 27.31 °Brix	Panelists liked higher moisture content
Valenzuela and Aguilera, (2015) a,b	Apples	Maltodextrin	60°C		No

2.1.2 Composite fruit leather

Several authors (Bains *et al*., 1989; Kumar *et al*., 2010; Diamante *et al*., 2013a, Akhtara *et al.*, 2014; Khan *et al.,* 2014) used two different fruits to make a composite fruit leather. Combining two fruits in one fruit leather product combines the advantages of the individual fruits.

Bains *et al*. (1989) processed apple-apricot leather using a fruit purée containing 82% apple purée, 16.5% apricot purée (a flavour component) and 1.5% apple juice concentrate. The fruit purée was poured in galvanised steel trays measuring 125 × 125 × 12 mm. The fruit purée was then placed in a cabinet dryer at 85°C with a flow rate of 4 m/s and relative humidity of 5% for 6.1 hours. This resulted in a good quality product. A two-stage operation with two hours of initial drying at 102°C followed by finish drying at 85°C for 3.5 hours also gave a good quality product.

Kumar *et al*. (2010) made blended guava-papaya leathers by mixing the pulps of guava and papaya in different ratios. Both the papaya and guava were washed, peeled and chopped into pieces. The seeds of the papaya were discarded and the fruit pieces were crushed in a mixer to make papaya pulp. The guava pulp was prepared by passing guava slices through a superfine pulper/finisher. The blended papaya and guava fruit pulps were then mixed in different ratios. Potassium metabisulphite (0.2%) was added as a preservative before the mixture was poured as a 10 mm thick layer into stainless steel trays, previously smeared with glycerol and then dried in a cross-flow cabinet dryer at 60°C.

Diamante *et al*. (2013a) prepared fruit leather using different levels of apple pulp, apple juice concentrate, blackcurrant concentrate and pectin powder, to obtain various fruit leather products to determine the effects of these three factors on various physicochemical and nutritional qualities. Approximately 315 g of the purée mixture was poured into aluminium pans with a non-stick surface (10 mm × 200 mm × 30 mm). The samples were then dried for 16 hours in a hot air dryer at 70°C with an air velocity of 200 mm/s.

Akhtara *et al.* (2014) evaluated the effect of different levels of apple pulp, date pulp, milk powder, pectin and starch on the physicochemical quality, sensory quality and shelf-life of apple-date fruit leather. They mixed all ingredients uniformly in a container and then heated the mixture at 80 – 100°C, with stirring, until 68 to 70°C was reached. The concentrated product was then spread into a tray coated with oil. The top surface of the mixture was levelled and then kept at room temperature (28 – 32℃) to allow the mixture to set. The leather was then cut to a suitable shapes and sizes and stored at ambient temperature.

Khan *et al.* (2014) dipped olive fruit in 2% sodium hydroxide for 36 hours in order to remove the bitterness. The olives and apples were then washed, peeled, trimmed, cut and dipped in a 1% citric acid solution to prevent oxidation. The fruit was then blended to a fine pulp. After making the fruit leather it was wrapped in aluminium foil and packed into air-tight plastic bags.

The additions and drying conditions, qualities and sensory data of composite fruit leathers are shown in Table 2.2. Sugar and pectin were usually added to composite fruit leathers. Fruit leathers were usually dried at 60 and 70℃ . The moisture content of final product ranged from 13% to 30%. Sensory evaluations (Akhtara *et al.*, 2014; Khan *et al.,* 2014) showed that panelists liked higher moisture and lighter colour of fruit leathers.

Table 2.2 Summary of published research and basic characteristics of fruit leather made from two fruits

References	Fruits	Additions	Drying conditions	Moisture content and water activity	Sensory evaluation
Bains *et al*., (1989)	Apples, apricot	Apple juice concentrate	70, 94°C		No
Kumar *et al*. (2010)	Guava, papaya	Potassium metabisulphite	60°C, 10 mm thick		No
Diamante *et al*. (2013a)	Apples, blackcurrant	Pectin	70°C, 16 h	21.1-29.2	No
Akhtara *et al.* (2014)	Apples, dates	Milk power, sugar, pectin,		30.14	Panelists liked higher moisture content
Khan *et al.* (2014)	Olives, apples			13.6	Panelists liked lighter colour

2.2 The qualities of fruit leather

The general process of making fruit leather involved the preparation of the fruit, making the fruit purée, then mixing ingredients and drying. These processes may vary, depending on the fruit used, the nature of the additives, as well as the drying method and technology (Diamante *et al*., 2014). Fruit leather can be evaluated in terms of its moisture content, water activity, colour, texture, sensory and nutritional qualities

2.2.1 Moisture content and water activity

The preservation of fruit leathers depends on the moisture content and water activity (typically 15 to 25%) (Perera, 2005). Both moisture content and water activity are the key factors which affect the shelf-life, safety, texture, flavour and smell of the fruit leather (Fontana, 2008). Bains *et al.* (1989) determined the moisture content by drying in a vacuum oven at 70°C for 24 hours. They determined the equilibrium moisture content in the dried purée by using the relationship based on diffusional drying. Demarchi *et al.* (2013) measured the water activity of apple leathers at 25°C by the AOAC hygrometric method 978.18 (AOAC, 1998), using a temperature-controlled Aqua Lab 3TE meter (Decagon Devices, Inc.). This method was also used by Diamante *et al.* (2013a).

The moisture content of fruit leathers is influenced through the style of fruit, drying system, temperature, humidity, sugar content and natural acidity. Water activity (a_w) refers to the volume of totally free water that may be available inside a food for biological reactions. It is a measurement in the water that is certainly not bound to elements inside the foods and it is, thus, readily available for microbial development. If water activity decreases, the quantity of microorganisms and their ability to grow will also decrease. All microorganisms possess a degree of water activity that they choose to grow within, and also have reduced limits for how “dry” a food could be in order for them to develop. For that motive, water activity is usually utilised being a method to protect food items and obtain a longer shelf-life. Water activity is definitely a significant factor in food processing as a substantial moisture content leads to toxin formation, microbial growth, and enzymatic and non-enzymatic reactions (Leung, 1984). The availability of water for microbial development, enzyme activity or chemical reactions, is a crucial component and determines the shelf-life of dried items or intermediate moisture food items (Perera, 2005).

Azeredo *et al*. (2006) found that a combination of low water activity (0.62), low pH (3.8) and a moisture content of 17.2% was required for mango fruit leathers to be shelf-stable for at least six months without the need for chemical preservation. Low moisture contents can inhibit microbial growth and prolong the shelf-life of a product. However, the very low levels of moisture content in fruit leathers negatively affected the texture quality (Huang and Hsieh, 2005). Generally, the water activity is lower when the moisture content is lower. The thermodynamic properties and sorption equilibrium of fruit leather were studied by Kaya and Kahyaoglu (2005). They showed that water activity was one of the most important quality factors for long-term storage because changing the water activity directly affected all chemical and microbial deterioration reactions.

2.2.2 Colour

Colour is one of the first characteristics noticed in food and in early times it was evaluated only subjectively, or with the use of colour comparison charts. The L* (lightness coefficient), a* and b* scale is recognised to present a better discrimination between produced with little colour variation within the darker area of the colour area and gives excellent discrimination for saturated colours (Barreiro *et al*., 1997). L*ranges from 0 (black) to 100 (white) on the vertical axis. The a* value represents the purple red (positive a* value) and blue-green (negative a* value) is on the horizontal axis. The b* represents yellow (positive b* value) and blue (negative b* value). For further manipulation, the chroma aspects of colour are used. Chroma achieves an index somewhat analogous to colour saturation and intensity. Chroma represents the hypotenuse of a right triangle made by joining points (0, 0), (a *, b*) and (a*, 0) (McGuire, 1992).

Colour is absolutely a critical quality attribute on the food items and bioprocessing industries, and influences consumers' selections and preferences. The colour of food items is governed with the chemical, biochemical and microbial and bodily alterations that occur during development, maturation, postharvest managing and processing of the foods (Pathare *et al.,* 2013).

Clydesdale (1993) considered that colour had a pivotal role in food choice, food preference/acceptability and influence taste thresholds, sweetness perception and enjoyment of consumers.

2.2.3 Texture

The textural properties of foods are critical for customer acceptance. Textural qualities such as toughness, chewiness, hardness and stickiness of fruit leathers were generally affected by the moisture content and drying temperature (Man and Sin, 1997). Huang and Hsieh (2005) found a positive correlation between texture attributes and consumer acceptance of fruit leathers made from pears. The addition of other ingredients, such as sugar and pectin, can also affect the texture of fruit leathers (Phimparian *et al*., 2011). The textural property of fruit leather is determined by measuring the force needed to puncture the fruit leather sheet using a texture analyser.

2.2.4 Ascorbic acid

Ascorbic acid (vitamin C) is a vital nutrient for humans and it could perhaps be an index of nutrient quality of the product. Ascorbic acid is also an antioxidant and, therefore, is helpful to stabilise a fruit leather product. Even so, ascorbic acid can be easily degraded, depending on temperature, light, pH, oxygen, presence of enzymes and metallic catalysers. Thus, many studies about food processes use ascorbic acid as a quality indicator (Santos and Silva, 2008). The fruit leathers are a good natural source of ascorbic acid in the diet (Akhtara *et al.*, 2014).

2.3 Factors affecting fruit leathers

The ingredients and additives used, such as sugar, pectin and fruit purée, have an influence on the physicochemical properties and sensory acceptability of fruit leathers. Drying conditions, including the method of drying, drying time, temperature and sample thickness, also affected the physicochemical properties and sensory acceptability of fruit leather (Maskan *et al*., 2002).

2.3.1 Pectin

Pectin is a high value, functional food ingredient widely used in the food industry. It is a high-molecular weight, biocompatible, non-toxic and anionic natural polysaccharide extracted from the cell walls of higher plants (Ridley *et al.*, 2001; Willats *et al.*, 2001; Willats *et al.*, 2006). It has regarded as a gelling/thickening agent and stabiliser resulting from its ability to develop aqueous gels and has been utilized in the production of desserts, fermented dairy products, fruit juice, fruit drink concentrates, jellies and jams (Willats *et al.*, 2006; Da Silva and Rao, 2007).

In fruit leather, pectin acts as a thickening agent and stabilises the mass of the product. Huang and Hsieh (2005) found that the amount of pectin used in the fruit leather will affect its textural qualities, such as toughness, chewiness, hardness and stickiness. They also found pectin was the most important factor that influenced all five texture profile analysis properties (hardness, cohesiveness, adhesiveness, springiness and chewiness) of pear fruit leather. The addition of pectin can be used to obtain a softer and more appealing fruit leather.

2.3.2 Sugar

Sugar is added to fruit leather as a sweetening agent and preservative (Gujral and Khanna, 2002; Jain and Nema, 2007; Gujral and Brar, 2003). Gujar and Khana (2002) indicated that sugar resulted in the highest acceptability in mango leather. Sugar gave the product a sweeter taste and increased the solids content when it was added to fruit leathers (Gujral and Brar, 2003). Huang and Hsieh (2005) found that the addition of corn syrup to pear fruit leather softened the fruit leather's texture when compared with the addition of other ingredients. Jain and Nema (2007) reported that the moisture content increased significantly with an increase in the sugar content of fruit leathers.

2.3.3 Fruit purée

Fruit purée can be mixed with sugar to enhance the texture, flavour and colour of the final product. Different types of fruit purée can be mixed together to prepare a fruit leather. It can also be added for colour preservation to avoid darkening during drying. (Huang and Hsieh, 2005; Raab and Oehler, 1999; Phimpharian *et al.*, 2011; Gujral and Khanna, 2002). Kumar *et al*. (2010) prepared papaya fruit leather by blending it with guava pulp to enhance the flavour of the papaya. Diamante *et al.* (2013a) studied the effects of different levels of apple juice concentrate, blackcurrant concentrate and pectin on the qualities such as moisture content, water activity, colour, texture and ascorbic acid content of apple-blackcurrant fruit leather. They discovered that the moisture content improved with increasing pectin level with larger increases at greater apple juice and blackcurrant concentrate levels. The water activity increased with increasing pectin and apple juice concentrate levels at very low pectin levels, but with decreasing apple juice concentrations, at large pectin ranges. The chroma of fruit leather increased with reducing pectin levels and had decreased values in the middle apple juice concentrate ranges. The puncturing force was greater with reducing apple juice concentrate degree but that has a lower value in the middle pectin ranges.

2.3.4 Drying conditions

Drying conditions also affected the physicochemical properties and sensory acceptability of fruit leather. During the drying process, the properties of the final product such as colour, texture, odour and nutrient are changed by the desirable or undesirable chemical or biochemical reactions. Diamante *et al*. (2014) reported that the method of drying and temperature affected the drying time and final moisture content of different fruit leathers. Lee and Hsieh (2008) studied thin layer drying of strawberry leather using 1.8, 2.7, and 3.6 mm sample thicknesses and drying temperatures of 50, 60, 70 and 80°C. The drying times for the strawberry leather determined that increasing the temperature at a constant sample thickness could reduce the time required to reach the equilibrium for moisture content. Demarchi *et al*. (2013) studied the effect of different temperatures (50, 60 and 70℃) on the hot-air drying rate and the retention of antioxidant capacity in apple leathers with, and without, the addition of potassium metabisulphite. The drying kinetics of apple leathers were accurately predicted by a one-term diffusive analytical solution for plane sheets using internal-external controls to predict mass transfer. The mass transfer Biot number was almost unity and the Arrhenius dependency of the effective diffusion coefficient with temperature provided an activation energy for drying of 20.6 kJ/mol. The retention of the antioxidant capacity of the apple leathers was low (6 - 16%) and decreased with increasing air temperatures even when the resulting drying times were shorter. In mathematical terms, this effect is explained by the higher activation energy needed for antioxidant capacity losses (above 31 kJ/mol), compared with that for drying samples to reach the safe-storage moisture content of 12% DM varied from 80 to 600 minutes in terms of the different drying temperatures and sample thicknesses. They found that the drying rates increased as the sample thickness decreased from 1.8 to 3.6 mm. Maskan *et al*. (2002) used hot air drying to make grape leather. The hot air drying experiments were conducted in a pilot plant tray dryer. The sample was dried from one side with hot air flowing parallel to the surface of the sample. The air velocities were 0.86 ± 0.03, 1.27 ± 0.04, 1.82 ± 0.09 m/s and the sample thicknesses were 0.71 ± 0.035, 1.53 ± 0.070, 2.20 ± 0.110 and 2.86 ± 0.071 mm. In this study, the hot air drying temperatures were 55, 65 and 75°C (dry bulb) and 27, 30 and 33°C (wet bulb), respectively. They found that the time required to reduce the moisture content to about 11% DM varied from 40 to 240 minutes, depending on the drying temperature and sample thickness.

2.4 Use of response surface methodology designs in dehydrated food products

Response surface methodology is a favoured approach to improve to and/or optimise the processes concerned. Response methodology suggests a surface that depicts the interactive impact between the variables inside a defined experimental area, which helps to know the connection in between the controllable variables. Through the multivariate optimisation procedure, the responses as well as components are two sorts of variables. The responses would be the dependent variables. The levels of the aspects are the independent variables that determine the response values (Ferreira *et al.*, 2007a; Ferreira *et al.*, 2007b).

The methodology permits reduction of the number of experimental trials required to judge the interaction impact amongst the variables inside the response and provide a massive degree of information, consequently, conserving time and labour. Response surface methodology is frequently employed for optimizing the whole method of dehydrating fruit products (King and Zall 1992; Pua *et al.*, 2010; Mercali *et al.* 2011; Diamante and Yamaguchi 2012, 2013). Box-Behnken design and central composite design are commonly used for response surface methodology experiments.

In essence, the central composite and Box-Behnken patterns are two procedures that enable a reduction in the range of experimental factors, but nonetheless provide a promising prediction of capacity. It has previously been recognized the risk of applying response surface methodology designs is useful to quantitatively review the interactions amid numerous independent elements and likewise to suggest an optimum formulation. The number of runs (N) required for the development of Box–Behnken design is defined as $N = 2k (k - 1) + C_0$, (where k is number of factors and C_0 is the number of central points). For comparison, number of experiments for a central composite design is $N = 2^k + 2k + C_0$ (Ferreira *et al.*, 2007a; Ferreira *et al.*, 2007b; Wei *et al.*, 2013).

Box–Behnken design is a spherical, rotatable, or virtually rotatable, second-order design. It is primarily based with a three-level incomplete factorial structure consisting of the centre level and center factors of the edges of the cube. It could be regarded as a few interlocking 2^2 factorial types in addition to a centre position. It ought to be emphasised that despite the fact that the look might be derived from a dice, it can be spherical, therefore the vertices on the cube are not coated by the style and, therefore, prediction all-around these factors is undoubtedly an extrapolation and may be avoided. The quantity of experimental points (N) is outlined with the expression $N = 2k (k - 1) + C_0$, where k could be the number of variables and C_0 could be the amount of centre details (Ferreira *et al.*, 2007b; Myers *et al.*, 2009). (Ferreira *et al.*, 2007b; Myers *et al.*, 2009; Zolgharnein *et al.*, 2013). Diamante *et al.* (2013a) established the effects of different levels of apple juice concentrate, blackcurrant concentrate and pectin on the moisture content, water activity, colour, texture and ascorbic acid content of apple-blackcurrant fruit leather using the Box–Behnken design. A response surface methodology optimisation using the Box–Behnken design was carried out on dried apple-blackcurrant cubes using different drying temperatures (50 to 70°C), blackcurrant concentrate levels (10 to 30%) and soaking times of (5 to 55 minutes) (Diamante and Yamaguchi, 2013). They found that the drying of blackcurrant-infused apple cubes consisted of only one falling rate period with no constant rate period.

Central composite design consists of a two degree factorial design getting 2^K points, where K is definitely the quantity of factors, a star design with 2K points to offer the design the ability of curvature description and centre point which is usually replicated to offer a measurement of reproducibility and model lack of fit (Ferreira *et al.*, 2007a; Myers *et al.*, 2009; Zolgharnein *et al.*, 2013).

2.5 Sensory evaluation

Sensory evaluation involves the measurement, quantification and interpretation of the sensory characteristics of foods and food products using human subjects as judges. Sensory evaluation leads the taster to choose one product as better than another or several others. Sensory evaluation can either be measured in a relative way (paired comparison, ranking), or is the degree of appreciation for a product, or in an absolute way, using an interval or ratio scale (Kemp *et al.*, 2011).

Sensory evaluation may be divided into two classes of screening; objective and subjective. In objective testing, a specific or trained panel evaluated the sensory characteristics of the product. The reactions of testers to the sensory properties of items are calculated from the subjective testing. The power of sensory evaluation is realised when these two things are merged to expose insights into the way where sensory properties give acceptance and emotional benefits. The linking of sensory properties to physical, chemical, formulation and/or approach variables then enables the product or service to be developed to deliver the best possible or ideal customer benefits (Kemp *et al.*, 2011).

Irwandi (1998) conducted sensory analyses for taste, texture, appearance, aroma and overall acceptability for durian leather using a 7-point hedonic scale (ranging from 1 = dislike extremely to 7 = like extremely). Azeredo *et al*. (2006) also used a 7-point hedonic scale for the colour, flavour and toughness attributes of mango fruit leather with no preservatives or added sugar. The sensory panel for mango leather studies comprised 20 trained and 30 non-trained panellists. For the evaluation of papaya leather, Kumar *et al*. (2010) used a 9-point hedonic scale and 10 semi-trained panellists to measure appearance, flavour, fruitiness, toughness and chewiness of the product.

The objectives of this study were to make a green kiwifruit-blackcurrant fruit leather product efficiently. The effects of level of sugar, blackcurrant purée and pectin and the different drying conditions of temperature, time and sample thickness, on the moisture content, water activity, colour, texture and ascorbic acid content of green kiwifruit-blackcurrant fruit leathers were determined and to obtain the optimised conditions for processing the fruit leather. Sensory evaluation was conducted to find the acceptability of the final green kiwifruit-blackcurrant fruit leather.

Chapter 3
Response surface methodology experiments

3.1 Experimental design

In this study, two different design methods were used; Box-Behnken and central composite design. These two methods were used to obtain the least number of experimental runs to achieve the aims of the experiment. In the first experiment the aim was to determine the best combination of sugar, blackcurrant purée, pectin to make a green kiwifruit-blackcurrant fruit leather using a Box-Behnken design. After the optimum combinations of ingredients had been determined, a central composite design was used to investigate the optimum combinations of drying time, drying temperature and sample thickness to identify the optimum processing conditions to efficiently produce a kiwifruit-blackcurrant fruit leather.

Overall, this study was conducted to determine the effects of different levels of six factors (the composition of three constituents and three processing conditions) on the selected qualities of green kiwifruit-blackcurrant fruit leather. If this study only used a Box-Behnken design, the number of experimental runs would be 64 while the number of experimental runs would be 80 if this study only used a central composite design. In the first experiment a Box-Behnken design only needed 16 different observations to investigate the optimum combinations of the three independent variables of sugar, blackcurrant purée and pectin. The central composite design only needed 18 different observations to investigate the three independent variables; drying time, drying temperature and sample thickness. Overall, only 34 experimental runs are required when the Box-Behnken and central composite design methods are used together. This is a more efficient way to investigate the interaction of the six different factors required to produce a fruit leather product.

3.2 Data and statistical analysis

The design and analysis of both response surface design methods was carried out using software Stat-Ease, Inc., Minneapolis, USA (Design-Expert® version 8.0.7.1). The data were analysed by multiple regression analysis using the least squares method. The regression coefficients of the linear, quadratic, and two factor interaction (2FI) involved in the model and their effects were generated by analysis of variance (ANOVA) and all the terms of the model were tested using an F test at $P \leq 0.05$. The regression coefficient (R^2), coefficient of variance (CV) and adequate precision of the models were used to examine the quality of the polynomial model which best fitted to the responses. The fitted polynomial equation was expressed as a response surface design in an effort to estimate the relationships between the responses and the independent variables to establish the best possible conditions.

3.3 Computing the multiple response optimization by desirability function

An optimisation procedure developed by Derringer and Suich (1980) in the Stat-Ease programme (Design-Expert® version 8.0.7.1), used a desirability function approach which is an efficient and now widely employed multi-criteria method for the optimisation of the analytical procedures. This procedure was used to identify the effects of different levels of sugar, blackcurrant purée and pectin, and of different drying conditions of temperature, time and sample thickness that would give the maximum moisture content and ascorbic acid content and minimum water activity, L*a*b* colour values, chroma and puncturing force.

Before this procedure could commence the upper and lower limits of the important parameters and responses needed to be set. These limits were summarised from previously published values given in Tables 2.1 and 2.2 and derived from evidence that panelists in the sensory evaluations liked higher moisture, lighter colour and softer texture of fruit leathers of fruit leathers. For a reasonable shelf life, the water activity should be reduced. Table 3.1 illustrates the limits that were set for each parameter that was used for achieving optimization of the responses.

Table 3.1 Limits of the parameters and responses for optimization using response surface methodology

Name	Goal	Lower limit	Upper limit
Sugar (%)	In the range	0	10
Blackcurrant purée (%)	In the range	3	9
Pectin (%)	In the range	0	4
Moisture content (g/100 g DM)	Maximize	18.19	26.6
Water activity	Minimize	0.5	0.76
L*	Minimize	29.4	33.97
a*	Minimize	6.11	9.8
b*	Minimize	0.77	6.65
Chroma	Minimize	6.16	11.69
Puncturing force (N/mm)	Minimize	0.61	9.61
Ascorbic acid content (mg/100 g DM)	Maximize	91.32	187.92

3.4 Box-Behnken design experiment

In the Box-Behnken design, sugar, blackcurrant purée and pectin were the three independent variables. These were coded into the design at three levels (Table 3.2). In this study, the number of factors is 3 and C_0 is 4. The output from Stat-Ease programme showing the 16 different samples required by the Box-Behnken response surface methodology design was shown in Table 3.3.

Table 3.2 Coding for the Box-Behnken design

Independent variables	Factor	Code Low -1	 Middle 0	 High +1
Sugar (%)	X_1	0	5	10
Blackcurrant (%)	X_2	3	6	9
Pectin (%)	X_3	0	2	4

Table 3.3 The output from Stat-Ease programme showing the 16 different samples required by the Box-Behnken response surface methodology design (Note coding: −1 = low level; 0 = middle level; 1 = high level)

	Uncoded factors			Coded factors		
Samples	Sugar (%)	Blackcurrant purée (%)	Pectin (%)	Sugar	Blackcurrant purée	Pectin
1	0	3	2	-1	-1	0
2	10	3	2	1	-1	0
3	0	9	2	-1	1	0
4	10	9	2	1	1	0
5	0	6	0	-1	0	-1
6	10	6	0	1	0	-1
7	0	6	4	-1	0	1
8	10	6	4	1	0	1
9	5	3	0	0	-1	-1
10	5	9	0	0	1	-1
11	5	3	4	0	-1	1
12	5	9	4	0	1	1
13	5	6	2	0	0	0
14	5	6	2	0	0	0
15	5	6	2	0	0	0
16	5	6	2	0	0	0

3.4.1 Preparation of green kiwifruit-blackcurrant purée mixture

Sixteen kg of firm, ripe, green kiwifruit (*Actinidia deliciosa* 'Hayward') were obtained on 15 May 2014 from a local supermarket in Christchurch, New Zealand. These were used in the Box-Behnken design experiment to establish the optimum combination of fresh kiwifruit purée, blackcurrant purée, sugar and pectin to make fruit leather. The fruit was sorted to remove damaged or over-ripe fruit. The green kiwifruit were stored at 4°C overnight. Using a hand held refractometer (Type 450 06, Bellingham + Stanley Ltd., Tunbridge Wells, Kent, UK), only fruit with a reading of between 13-15° Brix were selected. The green kiwifruit were then peeled, cored, sliced and blended for two minutes in a Cascade blender (model CE071BR, China) at room temperature. Three ingredients were then added to the kiwifruit purée; white sugar (Chelsea Refinery, Auckland, NZ), high methylester, slow set pectin powder (Classic AF401, Herbsteith & Fox KG., Neuenbürg, Germany) and blackcurrant purée (Barker's of Geraldine, South Canterbury, NZ) pectin following the formulations shown in Table 3.4. The blackcurrant purée was a special purée product that had also been sieved to remove seeds and large skin pieces and had been prepared without any additives, such as sugar and pectin. The blackcurrant purée was stored at -20°C and was thawed at 4°C overnight before it was used to make the fruit leather mixture.

A total of 1 kg purée mixture was made for each of the 16 different combinations of ingredients. The purée mixtures were poured into a 300 × 200 × 40 mm metal tray with a non-stick coating. Approximately 390 g of the purée mixture filled the tray. The purée was dried at 70℃ and a constant air flow of 0.20 m/s perpendicularly for 16 hours with a 6 mm starting sample thickness. A general process flow chart for the Box-Behnken design experiment is shown in Figure 3.1.

Table 3.4 The formulation of sixteen, 1 kg green kiwifruit – blackcurrant purée mixes

Samples	Sugar (g)	Blackcurrant purée (g)	Pectin (g)	Green kiwifruit purée (g)
1	0	30	20	950
2	100	30	20	850
3	0	90	20	890
4	100	90	20	790
5	0	60	0	940
6	100	60	0	840
7	0	60	40	900
8	100	60	40	800
9	50	30	0	920
10	50	90	0	860
11	50	30	40	880
12	50	90	40	820
13	50	60	20	870
14	50	60	20	870
15	50	60	20	870
16	50	60	20	870

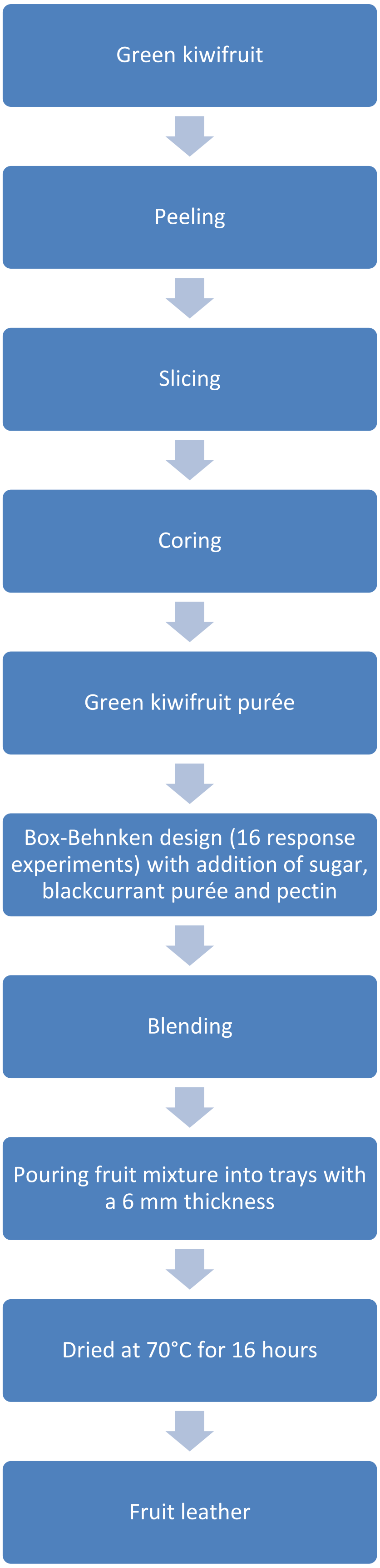


Figure 3.1 Flow diagram of the general process for the production of fruit leather in the Box-Behnken design experiment

3.4.2 Chemical analysis

3.4.2.1 Moisture content

The moisture content of the fruit leather samples was determined in triplicate using an oven (Watson Victor, Ltd., New Zealand) established at 105°C for 16 hours using Method 984.25 (AOAC, 2002).

3.4.2.2 Water activity

Water activity was determined in triplicate for each sample. The fruit leather samples were cut into approximately 2 mm × 2 mm pieces and placed in an Aqua Lab water activity meter CX-2 (Decagon Devices, Inc., Washington, DC, USA). The results were expressed as mean water activity per treatment at room temperature (20°C).

3.4.2.3 Colour determination

Colour values (CIE, $L^*a^*b^*$) of the different fruit leathers were determined using a Reflectance Chroma Meter CR 210 (Minolta Co. Ltd., Osaka, Japan). The instrument was calibrated before each measurement using a white ceramic tile ($L^* = 98.06$, $a^* = -0.23$, $b^* = 1.88$). Five measurements were taken from the different areas of each sample. The chroma value of the samples were calculated utilizing the equation chroma = $(a^{*2}+b^{*2})^{1/2}$, where a^* and b^* are colour values of the samples.

3.4.2.4 Texture

The texture analysis method was adapted from Diamante *et al*. (2013a). The textural properties of the fruit leather were determined by measuring the force necessary to puncture the fruit leather sheet making use of a texture analyser (Texture Analyzer Model: TA-XT plus, Serial No: 10 781, Stable Micro System, Surrey, UK) equipped with a 5 kg load cell. A heavy duty platform (HDP/90) which had a hole in the centre which was used to assist in the alignment the fruit leather sheet. A five hundred gram stainless steel cylinder with a hole in the centre was placed on top of the sample to carry it in place. A 2 mm cylindrical probe was used to puncture the sample. The test speed was set to 1.0 mm/s, the trigger force was set at 5 g and the travel distance of the probe was set to 10.0 mm. The 2 mm diameter probe was brought down to within 2 mm of the sample then the test was started and run until it punctured the sample. The different fruit leathers were measured 12 times at different points on the fruit leather samples. The collected data for puncturing force (kg) was analysed in XTRAD Dimension software from Stable Micro Systems and were expressed as mean values per sample. The data for puncturing force (kg) were converted to Newtons (n) using a factor of gravitational acceleration (g) of 9.80665 m/s^2. As the different samples had different variable thicknesses, the mean thicknesses of each sample were measured using a digital Vernier calliper (Insize Tools, Suzhou, China). The mean thickness was used to calculate the puncturing force per unit thickness (N/mm) for each sample.

3.4.2.5 Ascorbic acid

The method of Diamante *et al*. (2013a) was used to measure the ascorbic acid of the fruit leather. Triplicate fruit leather samples were prepared by macerating 10 g of the sample with 50 ml of 5% metaphosphoric acid in a mortar and pestle and then filtering through a Whatman (No. 4) filter paper. The extracted sample was measured immediately. Ten ml of filtrate was titrated with 2, 6-dichloroindophenol following AOAC Method 967.21. Measurements were determined using a modified Metrohm titrimetric method (Application bulletin No. 98/2e). The method used a Pt Titrode connected to a 670 Titroprocessor with sample changer with a 16-position 100 ml beaker carousel.

Data capture and equipment control were executed using a Tiamo software version 1.2.41 (Metrohm AG, Switzerland) (Diamante *et al*., 2013a).

3.5 The results of Box–Behnken Design Experiments

3.5.1 Dry matter, pH, ºBrix, L*a*b* colour values, chroma and ascorbic acid of the two fruit purées

The dry matter, pH, soluble solid, L*a*b* colour values, chroma and ascorbic acid of the two fruit purée mixes used to make fruit leather are shown in Table 3.5. Laaksonen *et al.* (2013) found that the pH of blackcurrant purée was 3.0, soluble solid was 14º Brix and the ascorbic acid was 100 mg/100 ml. These are similar to the values recorded in Table 3.5. In the study of Benlloch-Tinoco *et al.* (2014), the soluble solid of kiwifruit purée was 13.67º Brix, the ascorbic acid was 75.9 mg/100 g, the pH was 3.33 and the L*a*b* colour values were 40.17, -1.56, 30.70, respectively. Their soluble solid and pH values are similar to the values recorded in Table 3.5.

Table 3.5 Mean composition of the two fruit purée mixes used to make the fruit leathers

	Blackcurrant purée	Kiwifruit purée
Dry matter (g/100 g DM)	13.33 ± 0.01	12.69 ± 0.93
L*	94.26 ± 1.36	92.79 ± 0.36
a*	1.30 ± 0.28	0.94 ± 0.26
b*	2.21 ± 0.93	0.48 ± 0.08
Chroma	2.63 ± 0.43	2.44 ± 0.12
pH	4.10 ± 0.02	3.22 ± 0.01
Soluble solids (ºBrix)	15.07 ± 0.09	15.02 ± 0.05
Ascorbic acid (mg/100 g DM)	98.14 ± 0.01	91.94 ± 0.01

3.5.2 Box–Behnken response surface design analysis

The experimental response values of the selected qualities: moisture content, water activity, L*a*b* colour values, puncturing force and ascorbic acid content of green kiwifruit-blackcurrant fruit leather at various levels of sugar, blackcurrant purée and pectin, are presented in Table 3.6. The raw data for the moisture content (% wet basis and % dry basis), water activity (a_w), L*a*b* colour values and chroma, puncturing force and ascorbic acid content of different green kiwifruit-black currant fruit leather samples from Box-Behnken design experiments are shown in Appendix A to E.

Table 3.6 Mean response values of the Box–Behnken design experiments on the qualities of kiwifruit-blackcurrant fruit leather using different levels of sugar, blackcurrant purée and pectin, using 70°C drying temperature, 16 hours drying time and 6 mm sample thickness

Samples	Moisture content (g/100 g DM)	Water activity	L*	a*	b*	Chroma	Puncturing force (N/mm)	Ascorbic acid content (mg/100 g DM)
1	25.47 ± 3.46	0.50 ± 0.007	33.97 ± 0.87	9.52 ± 0.38	6.65 ± 0.58	11.69 ± 0.16	8.83 ± 1.35	172.05 ± 9.52
2	24.55 ± 1.61	0.76 ± 0.001	33.62 ± 0.48	9.69 ± 0.32	6.18 ± 0.27	11.49 ± 0.41	3.82 ± 1.17	91.32 ± 4.57
3	23.81 ± 2.24	0.60 ± 0.003	30.54 ± 1.07	7.86 ± 0.13	2.69 ± 0.72	8.41 ± 0.28	9.61 ± 0.17	187.92 ± 5.94
4	26.37 ± 2.47	0.62 ± 0.003	30.60 ± 0.50	7.71 ±0.37	2.25 ± 0.55	8.08 ± 0.49	2.26 ± 0.58	111.72 ± 2.45
5	18.19 ± 1.86	0.59 ± 0.002	30.46 ± 0.12	7.66 ±0.31	2.38 ± 0.20	8.02 ± 0.35	2.06 ± 0.19	163.43 ± 1.88
6	21.71 ± 1.61	0.61 ± 0.003	30.44 ± 0.13	7.59 ± 0.4	1.75 ± 0.09	7.79 ± 0.41	0.61 ± 0.05	131.9 ± 1.96
7	26.14 ± 7.03	0.58 ± 0.008	30.27 ± 0.12	9.54 ± 0.29	3.58 ± 0.16	10.20 ± 0.21	7.85 ± 2.25	112.07 ± 10.2
8	26.60 ± 5.59	0.58 ± 0.00	31.19 ± 0.25	9.47 ± 0.47	2.96 ± 0.17	9.93 ± 0.50	4.41 ± 0.93	100.18 ± 6.22
9	19.92 ± 1.80	0.67 ± 0.007	31.45 ± 0.20	7.87 ± 0.13	4.06 ± 0.04	8.85 ± 0.14	0.91 ± 0.13	173.84 ±7.15
10	19.90 ± 1.80	0.64 ± 0.003	29.40 ± 0.08	6.11 ± 0.24	0.77 ± 0.50	6.16 ± 0.25	1.37 ± 0.20	162.74 ± 9.01
11	25.91 ± 2.52	0.58 ± 0.003	31.43 ± 0.11	8.37 ± 0.16	4.70 ± 0.06	9.60 ± 0.15	7.55 ± 0.76	112.62 ± 2.96
12	24.12 ± 4.03	0.56 ± 0.003	29.84 ± 0.23	8.05 ± 0.09	1.80 ± 0.06	8.25 ± 0.09	7.06 ± 0.32	105.74 ± 3.37
13	22.64 ± 2.63	0.61 ± 0.003	31.72 ± 0.09	9.80 ± 0.10	3.06 ± 0.08	10.27 ± 0.1	5.39 ± 0.32	140.21 ± 3.99
14	23.78 ± 4.30	0.61 ± 0.003	31.33 ± 0.36	9.30 ± 0.44	3.13 ± 0.11	9.81 ± 0.45	5.00 ± 0.53	121.92 ± 8.45
15	23.47 ± 2.83	0.58 ± 0.004	31.48 ± 0.14	9.08 ± 0.19	2.89 ± 0.05	9.53 ± 0.18	5.10 ± 0.44	125.5 ± 1.95
16	23.14 ± 2.00	0.58 ± 0.008	32.02 ± 0.13	8.61 ± 0.27	2.91 ± 0.12	9.08 ± 0.29	7.55 ± 0.52	132.69 ± 2.71

The chemical and colour analysis of the 16 different fruit leather samples were then entered into the Box–Behnken design programme. The programme then attempted to fit four high degree polynomial models, linear, interactive (2FI), quadratic and cubic models to the data using the previously entered limits for each of the independent variables and the selected responses (Table 3.1). An adequacy model was performed on the experimental data to determine which model would give the best fit of the data. The results of the analysis of variance, goodness of fit and the adequacy of the models are summarised in Table 3.7.

Table 3.7 Adequacy of the model tested indicated that the linear model of puncturing force and ascorbic acid content, the quadratic model of responses of moisture content, L*a*b* colour values, chroma and a two-factor interaction (2FI) model of water activity

Source	SD	R^2	Prob > F	Remark	Source	SD	R^2	Prob > F	Remark
Moisture content					b*				
Linear	1.40	0.751	0.001		Linear	0.84	0.763	0.001	
Two-factor interaction	1.39	0.816	0.412		Two-factor interaction	0.97	0.764	0.998	
Quadratic	0.68	0.971	0.008	Suggested	Quadratic	0.28	0.987	0.000	Suggested
Water activity					Chroma				
Linear	0.049	0.385	0.109		Linear	0.88	0.691	0.002	
Two-factor interaction	0.039	0.699	0.080	Suggested	Two-factor interaction	1.00	0.706	0.925	
Quadratic	0.044	0.752	0.745		Quadratic	0.56	0.937	0.019	Suggested
L*					Puncturing force				
Linear	0.90	0.572	0.014		Linear	1.61	0.758	0.001	Suggested
Two-factor interaction	1.02	0.586	0.957		Two-factor interaction	1.78	0.778	0.845	
Quadratic	0.49	0.936	0.008	Suggested	Quadratic	1.43	0.904	0.145	
a*					Ascorbic acid content				
Linear	0.77	0.554	0.018		Linear	15.73	0.773	0.000	Suggested
Two-factor interaction	0.86	0.588	0.862		Two-factor interaction	17.84	0.781	0.952	
Quadratic	0.46	0.922	0.014	Suggested	Quadratic	19.71	0.822	0.721	

From Table 3.7, the adequacy of the output of the models tested indicated that the linear model of puncturing force and ascorbic acid content, the quadratic model of responses of moisture content, L*a*b* colour values, chroma and a two-factor interaction (2FI) model of water activity, were suggested for use in the model. Cubic models of all responses were rejected as their P valves were not significant and, therefore, could not be used for further modelling of the experimental data. The models were selected by the lower standard deviation (SD), significant P values and maximum R^2 values. For example the R^2 value for the quadratic and cubic models of moisture content were both high, but the P value of the cubic model was not significant. Therefore, the quadratic models had a good fit and could be used to predict the response of the moisture content under the experimental conditions. The quadratic models of L*a*b* colour values and chroma were selected for the same reason. The 2FI model of water activity gave the best fit for the R^2 value of 2FI as the model of water activity is higher than its linear model. The P value of the linear model for puncturing force and ascorbic acid content were highly significant. The P value of other models of puncturing force and ascorbic acid content were all higher than 0.05, which were not significant.

3.5.3 Model fitting

Mathematical models were developed to obtain a better understanding of the nature of the true relationships between the input variables and the output variables of the system under study. This approximate formula can be used to achieve an approximate idea of what would happen for a large number of input-parameter combinations. The estimated coefficients of predicted polynomial models are outlined in Table 3.7. An empirical relationship between independent variables and responses were described by polynomial equations with interaction terms, which were fitted with the experimental results obtained on the basis of the Box–Behnken experimental design. The final equations are shown below:

Moisture content = $23.26 + 0.70_{X1} - 0.21_{X2} + 2.88_{X3} + 0.87_{X1X2} - 0.77_{X1X3} - 0.44_{X2X3} + 1.24_{X1}^2 + 0.55_{X2}^2 - 1.34_{X3}^2$.

Water activity = $0.60 + 0.038_{X1} - 0.011_{X2} - 0.026_{X3} - 0.06_{X1X2} - 0.005_{X1X3} - 0.0025_{X2X3}$.

$L^* = 31.64 + 0.076_{X1} – 1.26_{X2} + 0.12_{X3} + 0.10_{X1X2} + 0.24_{X1X3} + 0.12_{X2X3} + 0.30_{X1}^2 + 0.24_{X2}^2 - 1.35_{X3}^2$.

$a^* = 9.20 - 0.015_{X1} - 0.71_{X2} + 0.78_{X3} - 0.08_{X1X2} + 0.000_{X1X3} + 0.36_{X2X3} + 0.23_{X1}^2 - 0.73_{X2}^2 - 0.86_{X}$.

$b^* = 3.00 - 0.27_{X1} - 1.76_{X2} + 0.51_{X3} - 0.075_{X1X2} + 0.0025_{X1X3} + 0.097_{X2X3} + 0.64_{X1}^2 + 0.80_{X2}^2 - 0.97_{X3}^2$.

Chroma = $9.67 - 0.13_{X1} - 1.34_{X2} + 0.90_{X3} - 0.032_{X1X2} - 0.001_{X1X3} + 0.34_{X2X3} + 0.51_{X1}^2 - 0.26_{X2}^2 - 1.20_{X3}^2$.

Puncturing force = $4.96 - 2.16_{X1} - 0.10_{X2} + 2.74_{X3}$.

Ascorbic acid content = $134.12 - 25.04_{X1} + 2.29_{X2} - 25.16_{X3}$.

where X_1, X_2 and X_3 are sugar, blackcurrant purée and pectin, respectively.

These equations were used to plot the following graphs in the section 3.5.5.

3.5.4 Statistical analysis

The adequacy and fitness of the models were tested by multiple regression analysis through the least square method. ANOVA analysis was used to check the significance of the models developed and ANOVA tables were generated, as shown in Appendix K. ANOVA is a statistical technique that subdivides the total variation in a set of data into component parts associated with specific sources of variation for the purpose of testing hypotheses for the parameters of the model (Maran *et al.*, 2013). As shown in Appendix K, ANOVA of the regression model shows that the models are significant. The ANOVA analysis indicated that the models developed adequately represented the actual relationship between the independent variables and responses.

The large F-value indicated that most of the variation in the response can be explained by the regression equation developed. The associated P-value was used to estimate whether F was large enough to indicate statistical significance and P-values lower than 0.05 indicated that the model developed and the terms were statistically significant (Maran *et al.*, 2014a, b).

3.5.5 Effect of addition variable

In this study, the variables (sugar, blackcurrant purée and pectin) were investigated for the selected qualities of fruit leathers using three factors at three levels using a Box–Behnken response surface design. 3D response surfaces plots were then used to represent the effect of added variables on the qualities of fruit leather. The response surface plots that showed the relative effects of any two variables when the remaining variable was kept constant are presented in Figures 3.2 to 3.9.

3.5.5.1 Effects of sugar and pectin levels on moisture content

Sugar and pectin were crucial parameters which affected the moisture content of the green kiwifruit-blackcurrant fruit leather. The surface plots for moisture content of the green kiwifruit-blackcurrant fruit leather, as affected by sugar and pectin levels, are shown in Figure 3.2. Overall, the surface plots show that the moisture content increases with increasing sugar and pectin levels.

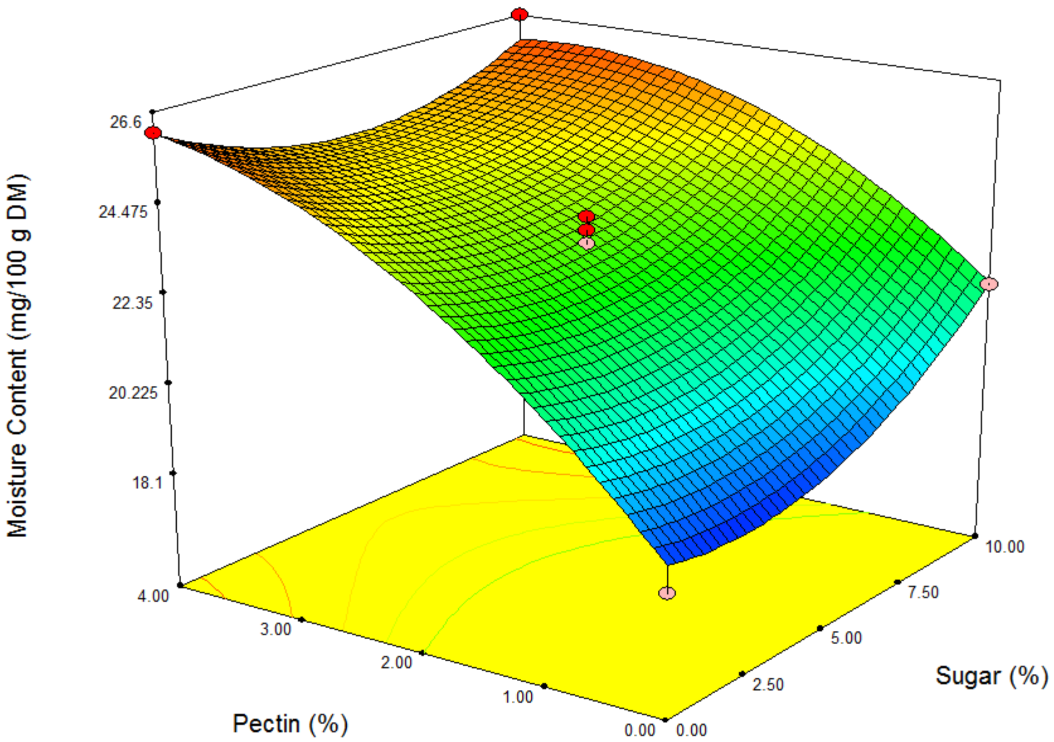


Figure 3.2 Response analysis for moisture content (g/100 g DM) of green kiwifruit-blackcurrant fruit leather, as affected by sugar and pectin levels, with a blackcurrant purée level of 6%

3.5.5.2 Effects of sugar and blackcurrant purée levels on water activity

Figure 3.3 shows that the surface plots for water activity of green kiwifruit-blackcurrant fruit leather as affected by the sugar and blackcurrant purée levels. The results suggest that the water activity of the products increases with increasing sugar and blackcurrant purée levels.

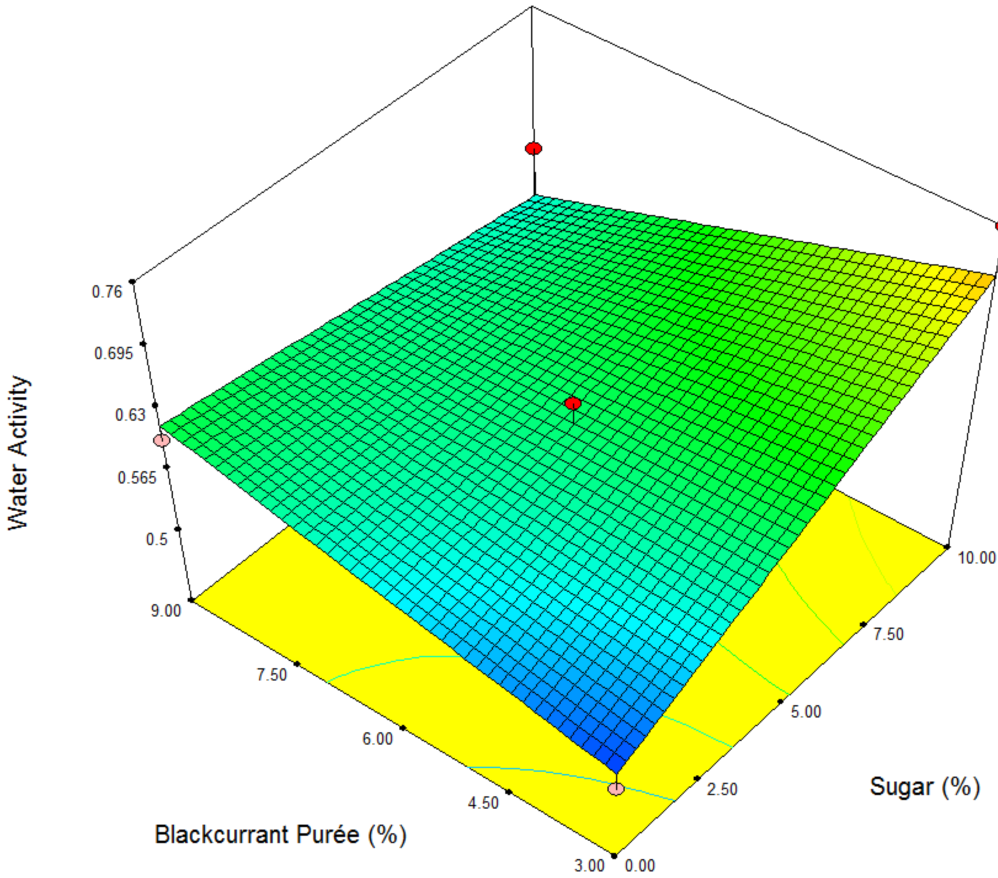


Figure 3.3 Response analysis for water activity of green kiwifruit-blackcurrant fruit leather, as affected by sugar and blackcurrant purée levels, with the pectin level kept at 2%

3.5.5.3 Effects of blackcurrant purée and pectin levels on L*

Figure 3.4 shows the interaction between blackcurrant purée and pectin on the L* of green kiwifruit-blackcurrant fruit leather. The results suggest that the L* of the products increases with increasing blackcurrant purée level. L* of the green kiwifruit-blackcurrant fruit leathers increases with increasing pectin level when the pectin level is below 3%. In contrast, the L* of the products decreases when the increasing pectin level is above 3%.

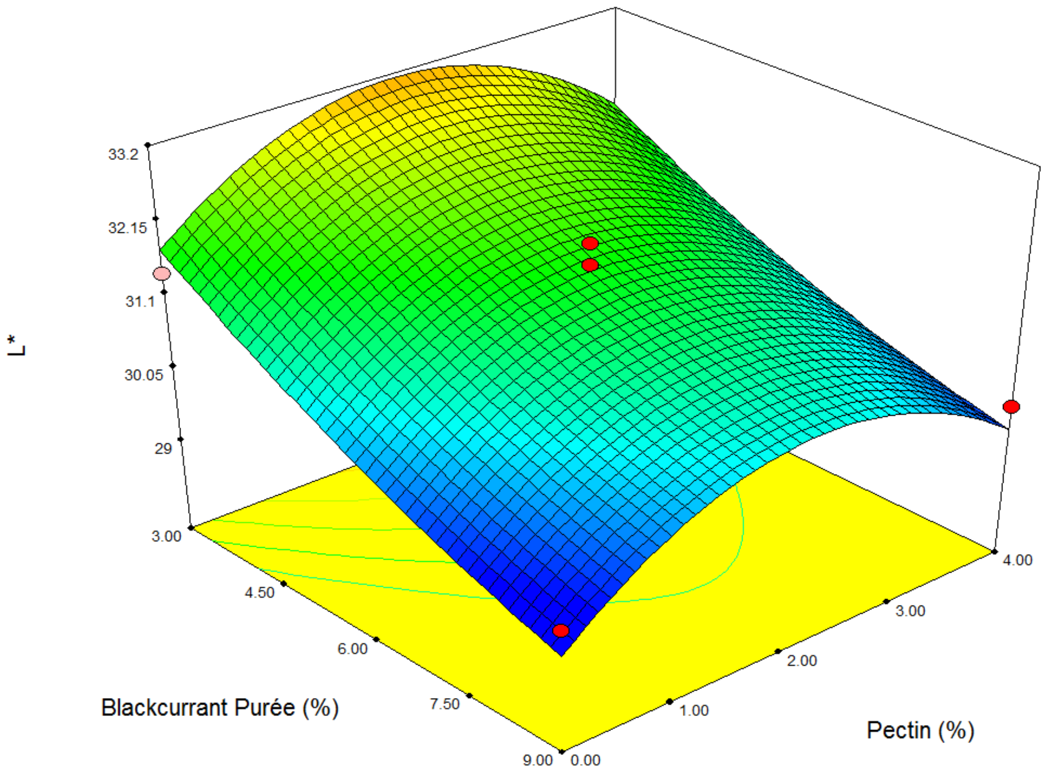


Figure 3.4 Response analysis for L* of green kiwifruit-blackcurrant fruit leather, as affected by blackcurrant purée and pectin levels, with the sugar level kept at 5%

3.5.5.4 Effects of blackcurrant purée and pectin levels on a*

The surface plots for a* of the green kiwifruit-blackcurrant fruit leather, as affected by blackcurrant purée and pectin levels, are depicted in Figure 3.5. The results show that a* of the products increases with increasing pectin level and decreasing blackcurrant purée level.

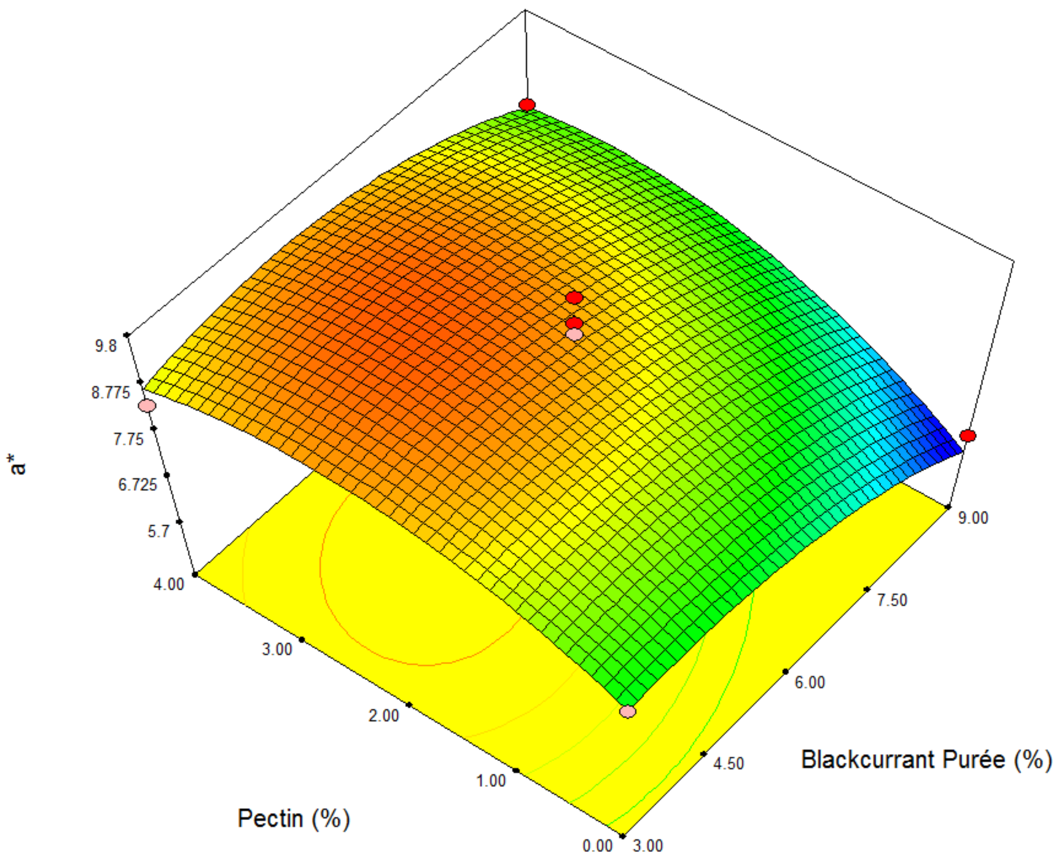
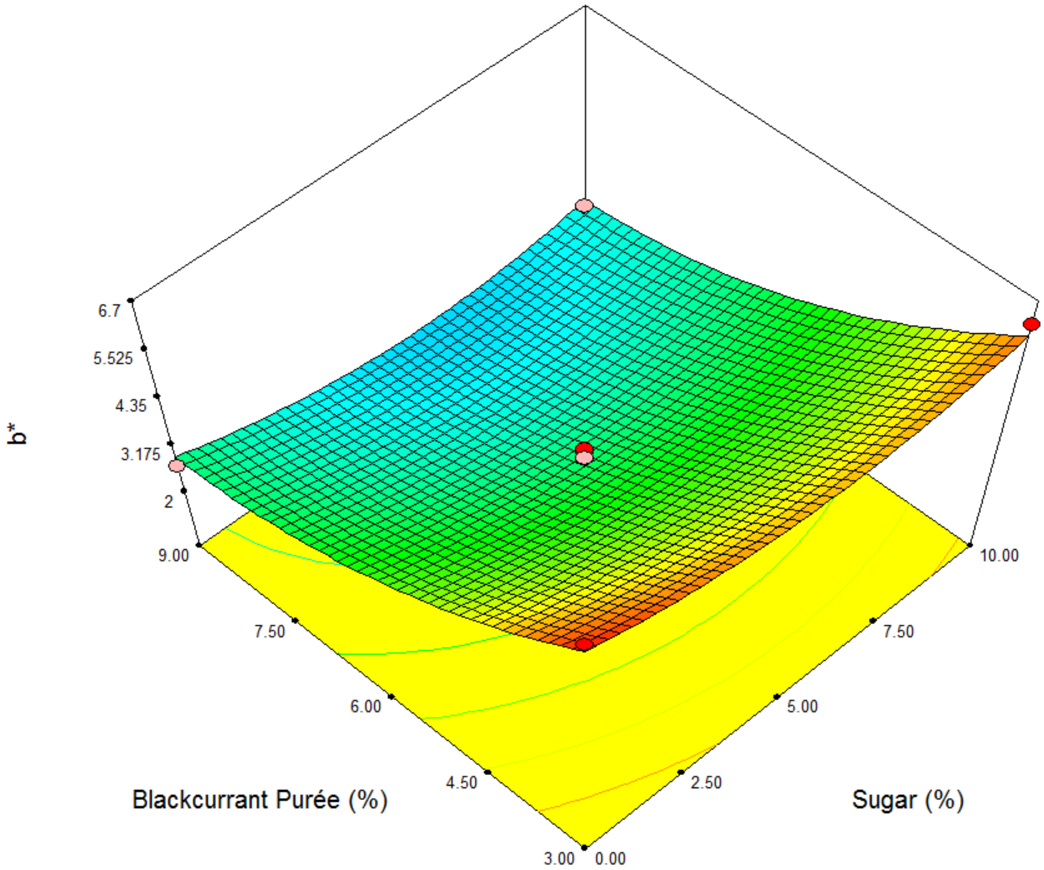


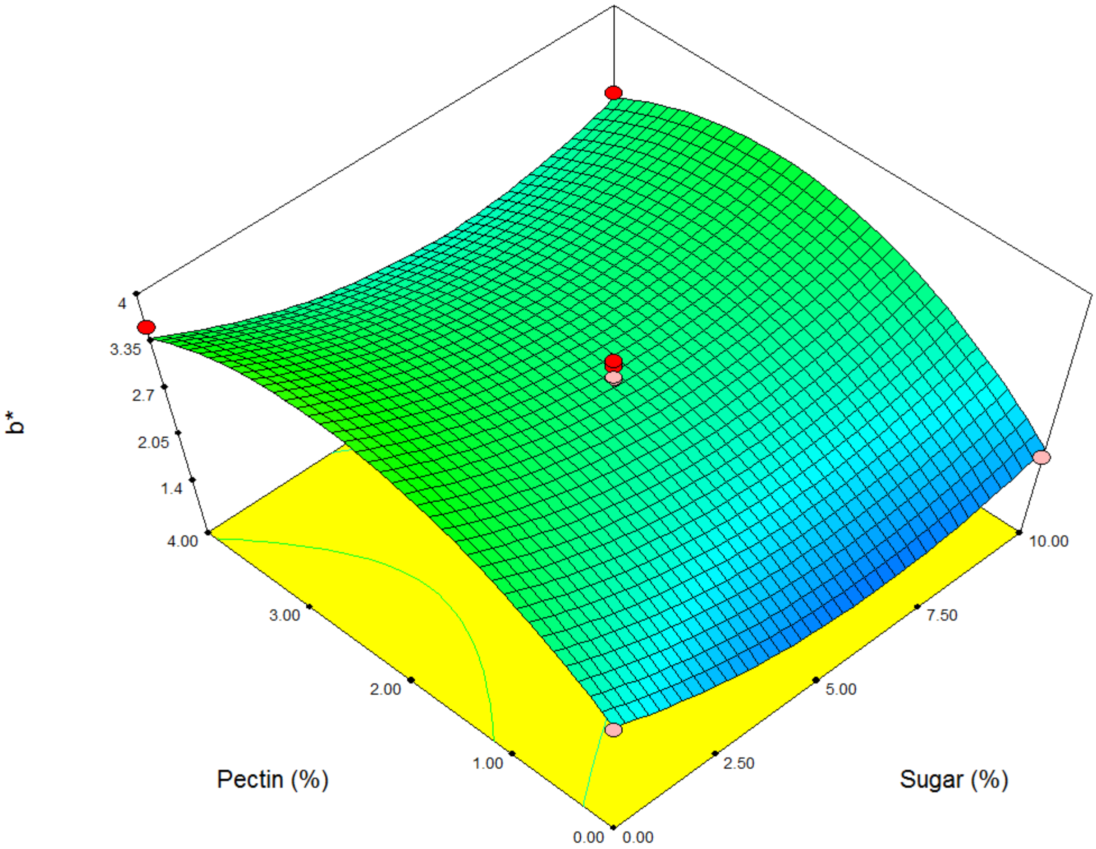
Figure 3.5 Response analysis for a* of green kiwifruit-blackcurrant fruit leather, as affected by blackcurrant purée and pectin levels, and with the sugar level kept at 5%

3.5.5.5 Effects of sugar blackcurrant purée and pectin levels on b*

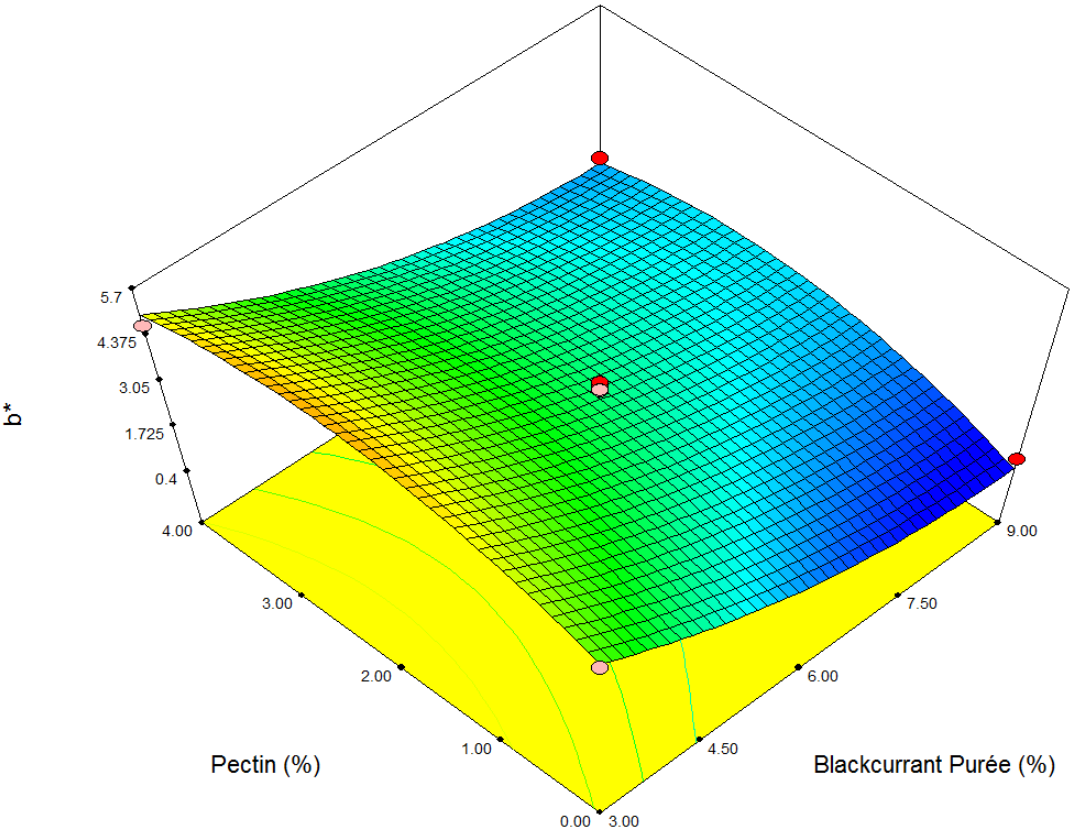
The surface plots for b* of the green kiwifruit-blackcurrant fruit leather, as affected by sugar, blackcurrant purée and pectin levels, are shown in Figures 3.6a, b and c. The results show that b* of the products increases with increasing blackcurrant purée level. The b* of the green kiwifruit-blackcurrant fruit leathers increases with increasing sugar level when the sugar level is above 5%. In contrast, the b* of the products decreases with increasing pectin level when the pectin level is below 5%. The b* of the green kiwifruit-blackcurrant fruit leathers increases with increasing pectin level when the pectin level is below 2%. In contrast, the b* of the products decreases with increasing pectin level when the pectin level is above 2%.



a) Pectin 2%



b) Blackcurrant purée 6%



c) Sugar 5%

Figure 3.6 Response analysis for b* of the green kiwifruit-blackcurrant fruit leather: (a) as affected by sugar and blackcurrant purée levels; (b) sugar and pectin levels; and (c) blackcurrant purée and pectin levels, with the third factor set at the middle level

3.5.5.6 Effects of blackcurrant purée and pectin levels on chroma

The surface plots for chroma of the green kiwifruit-blackcurrant fruit leather, as affected by sugar and blackcurrant purée levels, are shown in Figure 3.7. The results suggest that b* of the products increases with increasing pectin level and decreasing blackcurrant purée level.

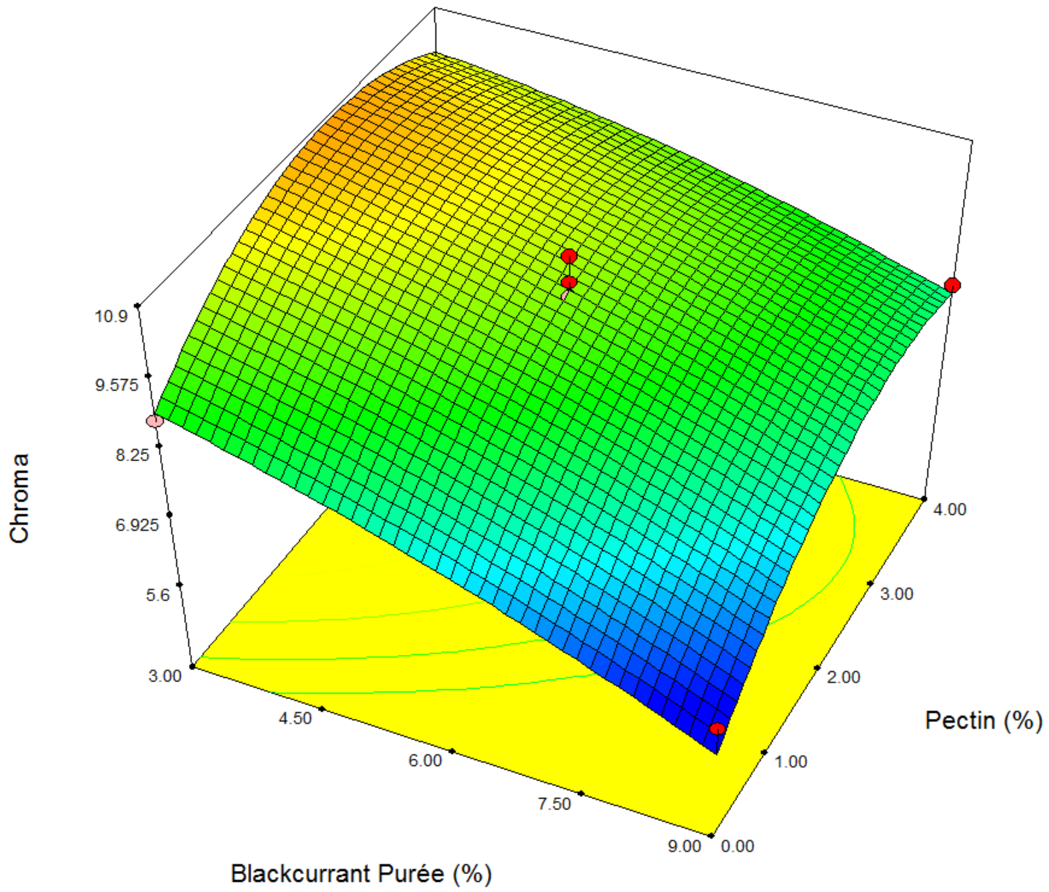


Figure 3.7 Response analysis for chroma of the green kiwifruit-blackcurrant fruit leather, as affected by blackcurrant purée and pectin levels, with the sugar level kept at 5%

3.5.5.7 Effects of sugar and blackcurrant purée levels on puncturing force

The surface plots for the puncturing force of the green kiwifruit-blackcurrant fruit leather, as affected by sugar and pectin levels, are shown in Figure 3.8. The results clearly show that the puncturing force of the products increases with increasing sugar and pectin levels.

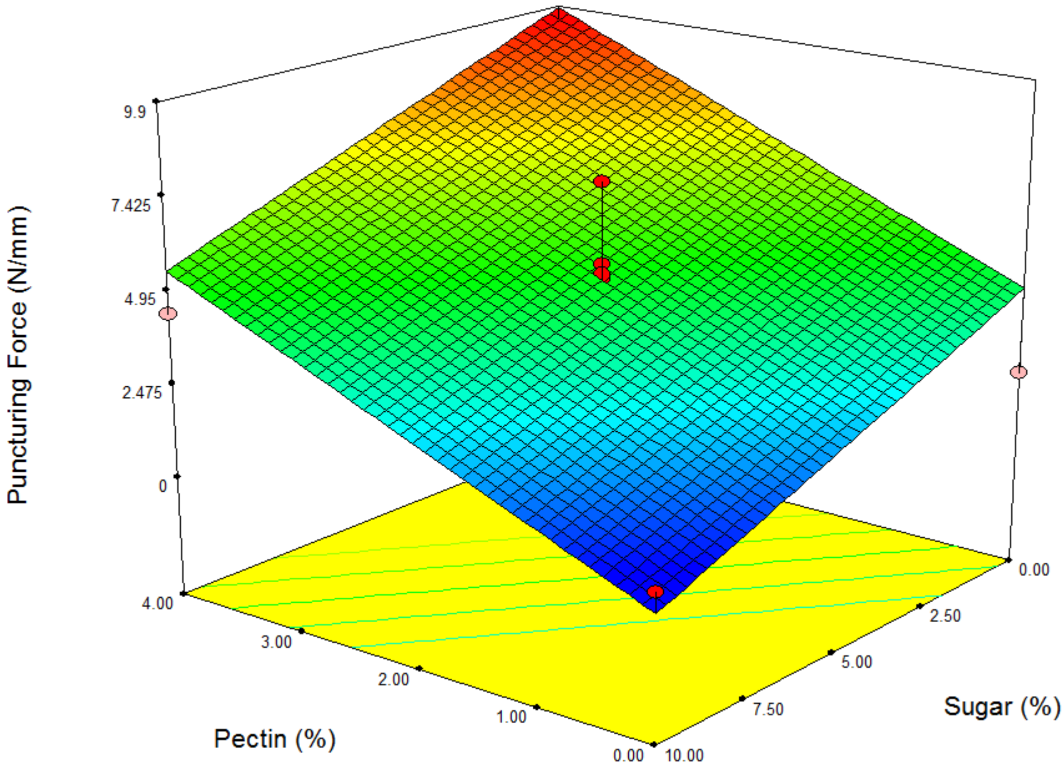


Figure 3.8 Response analysis for the puncturing force of the green kiwifruit-blackcurrant fruit leather, as affected by sugar and sugar level, with the blackcurrant purée level kept at 6%

3.5.5.8 Effects of sugar and blackcurrant purée levels on ascorbic acid content

The sugar and pectin are crucial parameters that affect the ascorbic acid content of green kiwifruit-blackcurrant fruit leather. The surface plots for ascorbic acid content of green kiwifruit-blackcurrant fruit leather, as affected by sugar and pectin levels, are shown in Figure 3.9. The results suggest that ascorbic acid content of the products increases with decreasing sugar and pectin levels.

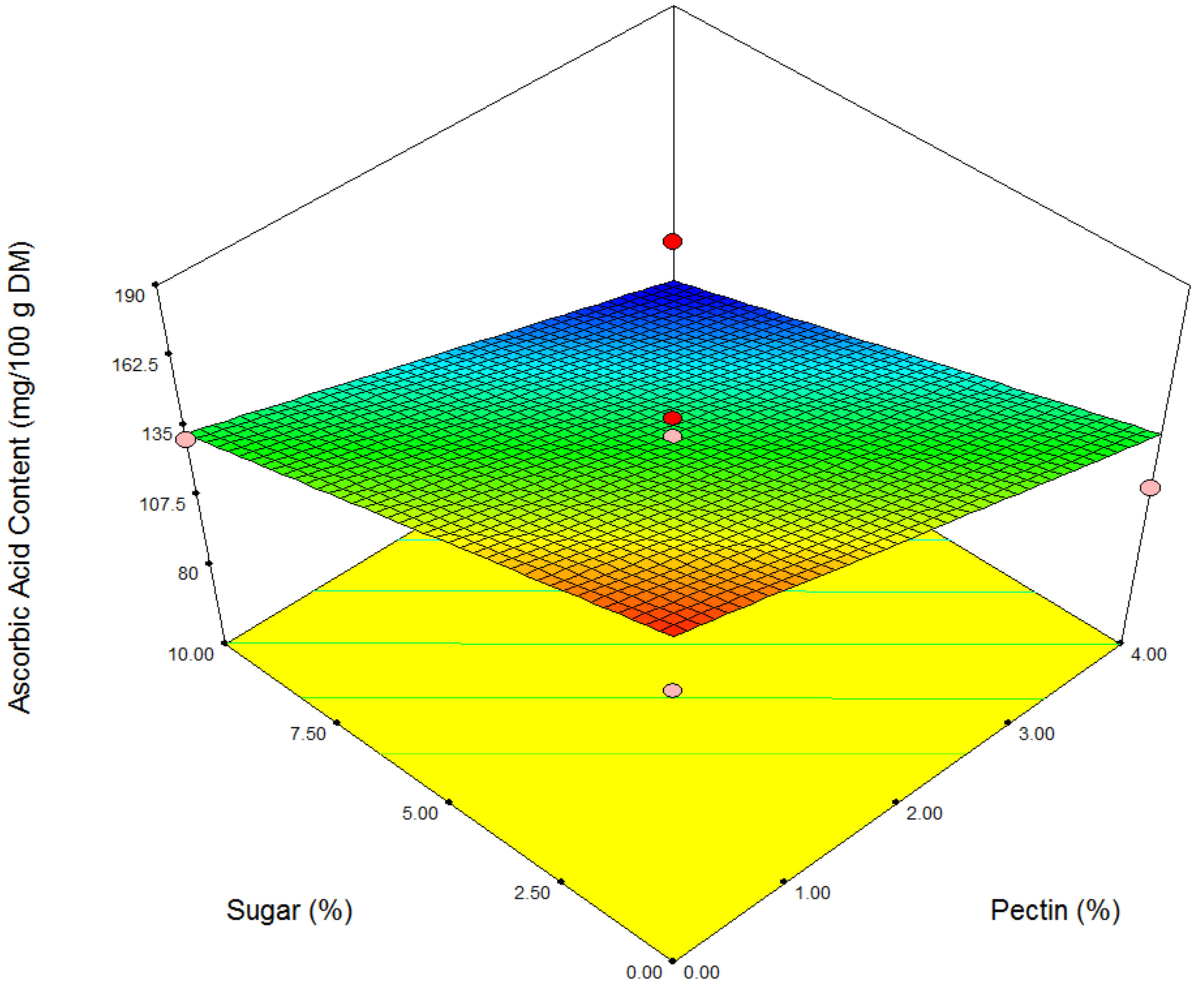


Figure 3.9 Response analysis for ascorbic acid content of green kiwifruit-blackcurrant fruit leather, as affected by sugar and pectin levels, with the blackcurrant purée level kept at 6%

3.5.6 Optimised conditions for making green kiwifruit-blackcurrant fruit leather using a Box–Behnken design experiment

A desirability function was used in the Design-Expert software to maximize moisture content, ascorbic acid content and minimize water activity, L*a*b* colour values, chroma and puncturing force simultaneously in the present study. The predicted values of the characteristics at these optimum conditions were used to predict the levels of sugar, blackcurrant purée and pectin and the results shown in Table 3.8. Puncturing force is very close to 0 N/mm just when the combinations are 10% sugar, 8.95% blackcurrant purée and 0.03% pectin.

Table 3.8 Predicted values for responses of kiwifruit-blackcurrant fruit leather at optimized combinations

Sugar (%)	Blackcurrant purée (%)	Pectin (%)	Moisture content (g/100 g DM)	Water activity	L*	a*	b*	Chroma	Puncturing force (N/mm)	Ascorbic acid content (mg/100 g DM)	Desirability
10	8.95	0.03	23.43	0.62	29.33	5.97	0.88	6.87	0.004	136.13	0.774
10	9	0.00	23.40	0.63	29.28	5.89	0.84	6.83	-0.04	136.52	0.774
10	8.93	0.00	23.35	0.62	29.30	5.94	0.85	6.86	-0.03	136.47	0.774

The programme then solved the problem of multiple responses through the use of a desirability function combining all responses into one measurement (Eren and Kaymak-Ertekin, 2007; Erbay and Icier, 2009). The overall desirability function (D) was calculated from the weighted geometric means of each individual desirability (di). Overall desirability ranges between D = 0 (a completely undesirable response), to D = 1 (a fully desired response), above which no further improvements can be made (Gadhe *et al*., 2013a). In this experiment, the responses were moisture content, water activity, L*a*b* colour values, chroma, puncturing force and ascorbic acid content.

$$D = \left(\prod_{i=1}^{n} \mathrm{di}\right)^{1/n}$$

where di indicates the individual desirabilities and n denotes the number of responses (8).

The overall desirability function was then calculated as the geometric means of 11 different response. It is interesting to note that the moisture content and the water activity of the final product had one of the lower individual desirability response (Figure 3.10). While these factors produced a desirable product, these values would need to be considered again as the moisture content and the water activity would be too high for products to be able to store satisfactory in a retail situation.

Once the Design-Expert programme had been given the upper and lower constraints for each of the important responses, the programme calculated the optimized mix of the different ingredients (Table 3.8). The predicted values for each of the responses could then be calculated and the desirability function was calculated from the fit of the response data within the upper and lower limits given to the programme.

The highest calculated desirability within the constraints set at the beginning of the analysis that the Design-Expert programme could give was 0.774. Diamante and Yamaguchi (2012) suggested a desirability value of equal or greater than 0.70 was acceptable food product formulations. The individual desirability for each response and the overall desirability can be seen in Figure 3.10.

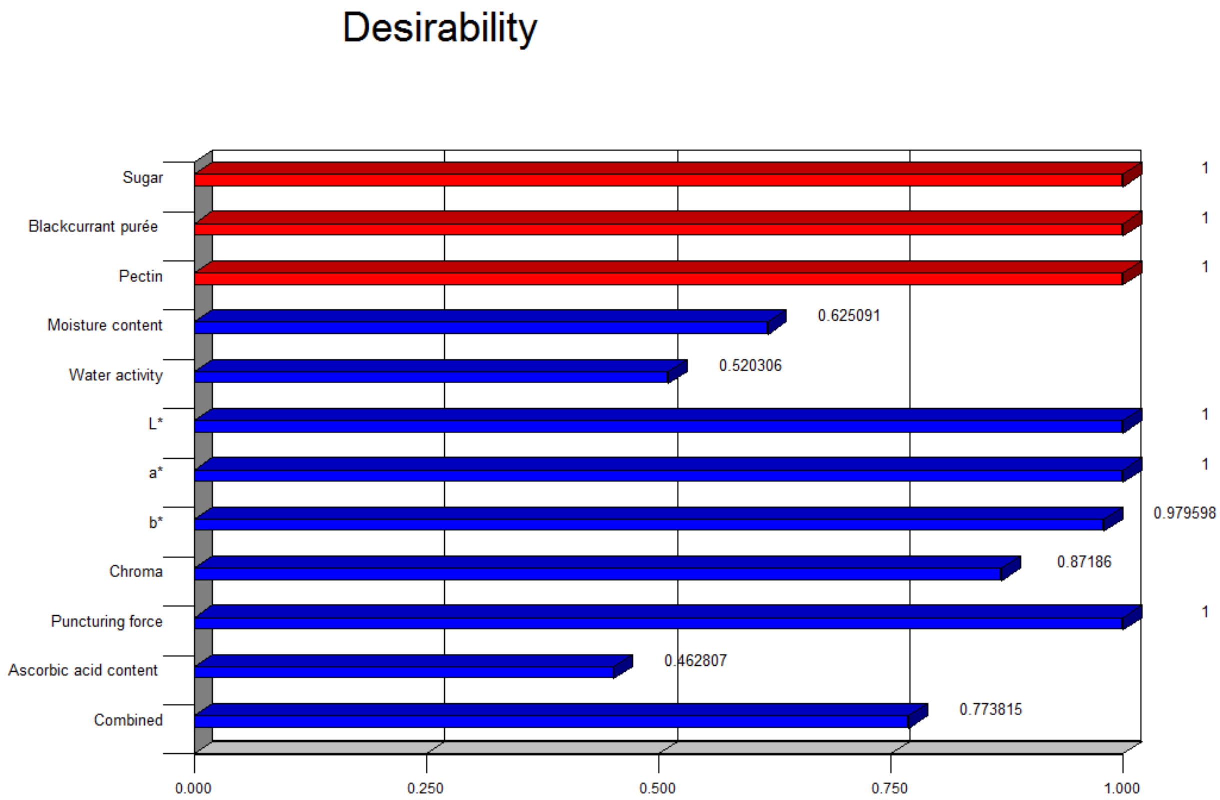


Figure 3.10 Bar graph representing individual desirability and combined desirability by a Box–Behnken design

The optimum combinations for the manufacture of kiwifruit-blackcurrant fruit leather using response surface analysis in the Design-Expert software were: 10% sugar, 8.95% blackcurrant purée and 0.03% pectin, with kiwifruit making up 81.02% of the remainder of the mix. Using these proportions to make a kiwifruit-blackcurrant fruit leather, the Design-Expert software predicted that the moisture content, would be 23.43 g/100 g DM; water activity, 0.62; L*, 29.33; a*, 5.97; b*, 0.88; chroma, 6.87; puncturing force, 0.004 N/mm and ascorbic acid content 136.13 mg/100 g DM.

3.6 Central composite design

In the central composite design, drying time, drying temperature and sample thickness were the three independent variables. These were coded into the design at three levels (Table 3.9). In this central composite design, the number of factors is 3 and C_0 is 4. The output from Stat-Ease programme showing the 18 different samples required by the central composite response surface methodology design was shown in Table 3.10.

Table 3.9 Coding for the central composite design

Independent variables	Factor	Code Low -1	 Middle 0	 High +1
Drying time (hours)	X_1	14	16	18
Drying temperature (°C)	X_2	60	70	80
Sample thickness (mm)	X_3	4	6	8

Table 3.10 The output from Stat-Ease programme showing the 16 different samples required by the central composite response surface methodology design (Note coding: −1 = low level; 0 = middle level; 1 = high level)

	Uncoded factors			Coded factors		
Samples	Drying time (hours)	Drying temperature (°C)	Sample thickness (mm)	Drying time	Drying temperature	Sample thickness
1	14	60	4	-1	-1	-1
2	18	60	4	1	-1	-1
3	14	80	4	-1	1	-1
4	18	80	4	1	1	-1
5	14	60	8	-1	-1	1
6	18	60	8	1	-1	1
7	14	80	8	-1	1	1
8	18	80	8	1	1	1
9	14	70	6	-1	0	0
10	18	70	6	1	0	0
11	16	60	6	0	-1	0
12	16	80	6	0	1	0
13	16	70	4	0	0	-1
14	16	70	8	0	0	1
15	16	70	6	0	0	0
16	16	70	6	0	0	0
17	16	70	6	0	0	0
18	16	70	6	0	0	0

Table 3.11 illustrates the limit of each parameter that was used for achieving optimization of the eight responses using a central composite design. Sensory evaluations (Chan and Cavaletto, 1978; Irwandi *et al.*, 1998; Vijayanand *et al.*, 2000; Huang and Hsieh, 2005; Vatthanakul *et al.*, 2010; Sharma *et al.*, 2013; Safdar *et al.*, 2014; Akhtara *et al.*, 2014; Khan *et al.*, 2014) showed that panelists usually liked higher moisture, lighter colour and softer texture of fruit leathers. The higher ascorbic acid content

means more nutritional value. So the goal of the maximize moisture content and ascorbic acid content and the minimize thickness, L*a*b* colour values and chroma and puncturing force were chosen.

Table 3.11 Limits of the parameters and responses for optimization using a central composite design

Name	Goal	Lower limit	Upper limit
Drying time (h)	In the range	14	18
Drying Temperature(°C)	In the range	60	80
Sample thickness (mm)	In the range	4	8
Moisture content (g/100 g DM)	Maximize	13.83	43.08
Water activity	Minimize	0.41	0.76
L*	Minimize	27.4	35.46
a*	Minimize	6.75	10.15
b*	Minimize	1.51	7.99
Chroma	Minimize	7.04	11.94
Puncturing force (N/mm)	Minimize	0.26	8.32
Ascorbic acid content (mg/100 g DM)	Maximize	48.9	207.83

3.6.1 Preparation of green kiwifruit-blackcurrant purée mixture

Eighteen kg of firm, ripe, green kiwifruit (*Actinidia deliciosa* 'Hayward') were obtained on 10 July 2014 from a local supermarket in Christchurch, New Zealand. These were used in the central composite design experiment to establish the optimum drying conditions of drying time, drying temperature and sample thickness to make fruit leather. Other materials such as sugar, pectin and blackcurrant purée and store conditions were same as the Section 3.4.1.

In the central composite design experiment, the fruit mixtures were prepared using the formulation optimised by the Box-Behnken design following the conditions: 10% sugar, 8.95% blackcurrant purée and 0.03% pectin, with kiwifruit making up 81.02% of the remainder of the mix. Eighteen samples were dried using different drying temperatures, drying times and sample thicknesses, based on a central composite design with three independent factors (Table 3.8). A general process flow chart for the central composite design experiment is shown in Figure 3.11.

3.6.2 Chemical analysis

The moisture content, water activity, colour values (CIE, L*a*b*), texture and ascorbic acid of the fruit leather samples were determined as in section 3.4.2.

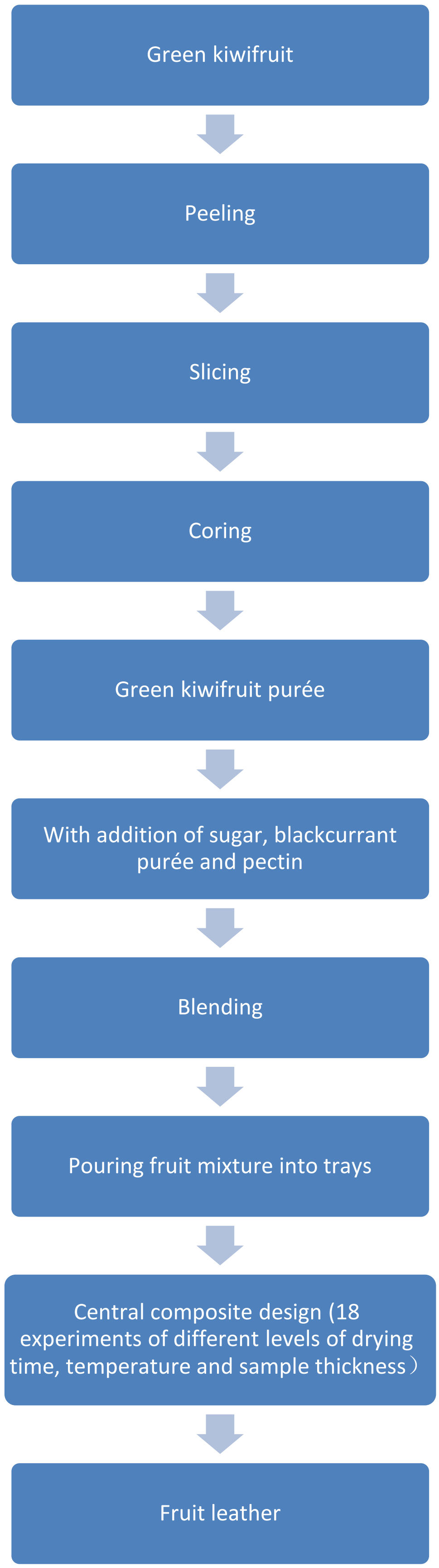


Figure 3.11 Flow diagram of the general process for the production of fruit leather in the central composite design experiment

3.7 The results of central composite response experiments

3.7.1 Central composite response surface design analysis

In this study, three factors at three levels of the central composite response surface design, were employed to optimise the individual and interactive levels of the added variable on the qualities of green kiwifruit-blackcurrant fruit leather selected. The experimental response values of the selected qualities for, moisture content, water activity, L*a*b* colour values, chroma, puncturing force and ascorbic acid content of green kiwifruit-blackcurrant fruit leather, are presented in Table 3.12. The raw data for the moisture content (% wet basis and % dry basis), water activity (a_w), L*a*b* colour values and chroma, puncturing force and ascorbic acid content of different green kiwifruit-black currant fruit leather samples from central composite response surface design experiments are shown in appendix F to J.

Table 3.12 Mean response values of the central composite design experiments on the qualities of kiwifruit-blackcurrant fruit leather using different levels of drying temperature, drying time and sample thickness using 10% sugar, 8.95% blackcurrant purée and 0.03% pectin level

Samples	Moisture content (g/100 g DM)	Water activity	L*	a*	b*	Chroma	Puncturing force (N/mm)	Ascorbic acid content (mg/100 g DM)
1	21.68 ± 1.34	0.59 ± 0.002	30.87 ± 0.07	7.7 ± 0.11	1.96 ± 0.07	7.95 ± 0.11	3.31 ± 0.47	109.2 ± 1.42
2	20.95 ± 1.44	0.56 ± 0.006	30.56 ± 0.17	10.15 ± 0.91	1.83 ± 0.18	10.31 ± 0.93	1.55 ± 0.10	103.56 ± 1.52
3	15.01 ± 1.79	0.45 ± 0.003	32.79 ± 0.35	7.49 ± 0.08	5.05 ± 0.15	9.04 ± 0.1	6.49 ± 0.55	50.33 ± 4.26
4	13.83 ± 0.79	0.41 ± 0.007	34.92 ± 0.19	8.79 ± 0.10	7.74 ± 0.15	11.72 ± 0.15	8.32 ± 0.75	48.9 ± 1.10
5	43.08 ± 6.98	0.76 ± 0.005	27.4 ± 0.34	6.82 ± 0.23	1.73 ± 0.13	7.04 ± 0.24	0.34 ± 0.00	207.83 ± 8.78
6	36.07 ± 3.76	0.74 ± 0.004	28.57 ± 1.03	6.99 ± 0.12	1.51 ± 0.11	7.15 ± 0.14	0.26 ± 0.06	178.36 ± 3.63
7	20.31 ± 1.82	0.56 ± 0.007	31.1 ± 0.19	7.43 ± 0.13	3.64 ± 0.06	8.27 ± 0.14	1.33 ± 0.4	91.22 ± 3.93
8	17.67 ± 2.49	0.46 ± 0.006	34.15 ± 0.10	8.58 ± 0.06	6.4 ± 0.09	10.7 ± 0.08	2.71 ± 0.4	73.89 ± 1.70
9	26.41 ± 2.10	0.59 ± 0.008	30.07 ± 0.13	7.22 ± 0.16	2.11 ± 0.16	7.53 ± 0.21	2.41 ± 0.5	146.73 ± 1.05
10	20.6 ± 0.33	0.53 ± 0.004	31.84 ± 0.32	7.46 ± 0.09	3.59 ± 0.06	8.28 ± 0.09	0.91 ± 0.09	98.97 ± 1.21
11	31.22 ± 5.46	0.63 ± 0.003	30.34 ± 0.20	7.53 ± 0.15	1.91 ± 0.04	7.77 ± 0.15	0.81 ± 0.01	166.8 ± 12.1
12	15.21 ± 1.56	0.45 ± 0.001	35.46 ± 0.36	8.87 ± 0.05	7.99 ± 0.16	11.94 ± 0.11	7.66 ± 1.43	58.59 ± 5.03
13	18.4 ± 1.23	0.46 ± 0.005	32.04 ± 0.15	8.99 ± 0.27	3.47 ± 0.09	9.64 ± 0.28	8.01 ± 0.12	83.05 ± 0.69
14	28.7 ± 0.54	0.63 ± 0.006	29.78 ± 0.24	6.75 ± 0.08	2.07 ± 0.10	7.06 ± 0.10	0.74 ± 0.19	143.83 ± 4.88
15	23.73 ± 1.93	0.52 ± 0.005	31.11 ± 0.17	7.53 ± 0.09	2.43 ± 0.08	7.92 ± 0.1	1.57 ± 0.26	136.46 ± 3.38
16	22.82 ± 2.13	0.51 ± 0..004	31.29 ± 0.10	7.65 ± 0.09	2.51 ± 0.08	8.05 ± 0.09	1.98 ± 0.22	120.34 ± 1.98
17	23.76 ± 1.90	0.52 ± 0.004	31.18 ± 0.25	7.91 ± 0.08	2.16 ± 0.14	8.2 ± 0.08	3.31 ± 0.61	141.22 ± 1.68
18	23.56 ± 1.66	0.52 ± 0.001	31.03 ± 0.09	7.93 ± 0.23	2.22 ± 0.09	8.24 ± 0.24	1.55 ± 0.31	131.67 ± 3.88

The chemical and colour analysis of the 18 different fruit leather samples were then entered into the central composite design program. The program then attempted to fit four high degree polynomial models, linear, interactive (2FI), quadratic and cubic models to the data using the previously entered limits for each of the independent variables and the selected responses (Table 3.13). An adequacy model was performed on the experimental data to determine which model would give the best fit of the data. The results of the analysis of variance, goodness of fit and the adequacy of the models are summarised in Table 3.13.

From Table 3.13, the adequacy of the output of the models tested indicated that the linear model of puncturing force and ascorbic acid content, the quadratic model of responses of water activity, L*and b* colour values, chroma and a two-factor interaction (2FI) model of moisture content and a* colour values were suggested for use in the model. Although the P value of the linear and the 2FI models were similar, the interactive (2FI) model was selected as the R^2 value of the 2FI model of moisture content was higher than for the linear model. The R^2 value of the 2FI model of a* was higher than for the linear model. The R^2 values for the quadratic and cubic models of water activity were 0.986 and 0.995, respectively. But the P value of the cubic model was 0.289, which was not significant. Therefore, the quadratic model had a good fit and could be used to predict the response of water activity under the experimental conditions. The P values of the linear and quadratic models of water activity for L*and b* were all lower than 0.05 but the R^2 value of the quadratic model of these three qualities were higher than the linear models, so the quadratic models were chosen. A linear model for puncturing force and ascorbic acid content were suggested. The P value of the linear models were lower than 0.005. The P value of the other models for puncturing force and ascorbic acid content were all higher than 0.05, which were not significant.

Table 3.13 Adequacy of the model tested for all central composite design responses

Source	SD	R^2	Prob > F	Remark	Source	SD	R^2	Prob > F	Remark
Moisture content					b*				
Linear	2.84	0.883	< 0.0001		Linear	1.15	0.746	0.000	
Two-factor interaction	0.94	0.990	< 0.0001	Suggested	Two-factor interaction	1.11	0.812	0.326	
Quadratic	1.09	0.990	0.982		Quadratic	0.69	0.947	0.014	Suggested
Water activity					Chroma				
Linear	0.032	0.910	< 0.0001		Linear	0.95	0.684	0.001	
Two-factor interaction	0.027	0.947	0.107		Two-factor interaction	0.96	0.742	0.507	
Quadratic	0.017	0.986	0.012	Suggested	Quadratic	0.72	0.897	0.0519	Suggested
L*					Puncturing force				
Linear	0.87	0.848	< 0.0001		Linear	1.61	0.715	0.000	Suggested
Two-factor interaction	0.76	0.908	0.125		Two-factor interaction	1.58	0.784	0.369	
Quadratic	0.40	0.982	0.003	Suggested	Quadratic	1.47	0.864	0.273	
a*					Ascorbic acid content				
Linear	0.64	0.569	0.007		Linear	17.66	0.872	< 0.0001	Suggested
Two-factor interaction	0.54	0.760	0.082	Suggested	Two-factor interaction	15.64	0.921	0.136	
Quadratic	0.53	0.832	0.387		Quadratic	12.12	0.965	0.072	

3.7.2 Model fitting

The empirical relationship between the independent variables and responses were expressed by polynomial equations with interaction terms that were fitted with the experimental results obtained on the basis of central composite responses design. The final equations are presented below:

Moisture content = $23.50 - 1.74_{X1} - 7.10_{X2} + 5.60_{X3} + 0.49_{X1X2} - 0.97_{X1X3} - 3.42_{X2X3}$.

Water activity = $0.53 - 0.025_{X1} - 0.095_{X2} + 0.068_{X3} - 0.011_{X1X2} - 0.\ 00625_{X1X3} - 0.\ 0024_{X2X3} + 0.026_{X1}{}^2 + 0.\ 005833_{X2}{}^2 + 0.011_{X3}{}^2$.

$L^* = 31.37 + 0.78_{X1} + 2.07_{X2} - 1.02_{X3} + 0.54_{X1X2} + 0.30_{X1X3} + 0.38_{X2X3} - 0.64_{X1}{}^2 + 1.30_{X2}{}^2 - 0.69_{X3}{}^2$.

$a^* = 7.88 + 0.53_{X1} + 0.20_{X2} + 0.78_{X3} - 0.021_{X1X2} - 0.30_{X1X3} + 0.47_{X2X3}$.

$b^* = 2.74 + 0.66_{X1} + 2.19_{X2} - 0.47_{X3} + 0.73_{X1X2} - 0.0025_{X1X3} - 0.27_{X2X3} - 0.31_{X1}{}^2 + 1.79_{X2}{}^2 - 0.39_{X3}{}^2$.

$\text{Chroma} = 8.27 - 0.83_{X1} + 1.14_{X2} - 0.84_{X3} + 0.33_{X1X2} - 0.31_{X1X3} + 0.29_{X2X3} - 0.53_{X1}{}^2 + 1.42_{X2}{}^2 - 0.089_{X3}{}^2$.

$\text{Puncturing force} = 2.96 - 0.013\ _{X1} + 2.02_{X2} - 2.23\ _{X3}$.

$\text{Ascorbic acid content} = 116.16 - 10.16\ _{X1} - 44.28_{X2} + 30.01\ _{X3}$.

where X_1, X_2 and X_3 are drying temperature, drying time and sample thickness, respectively.

These equations were used to plot the following graphs in the section 3.7.4.

3.7.3 Statistical analysis

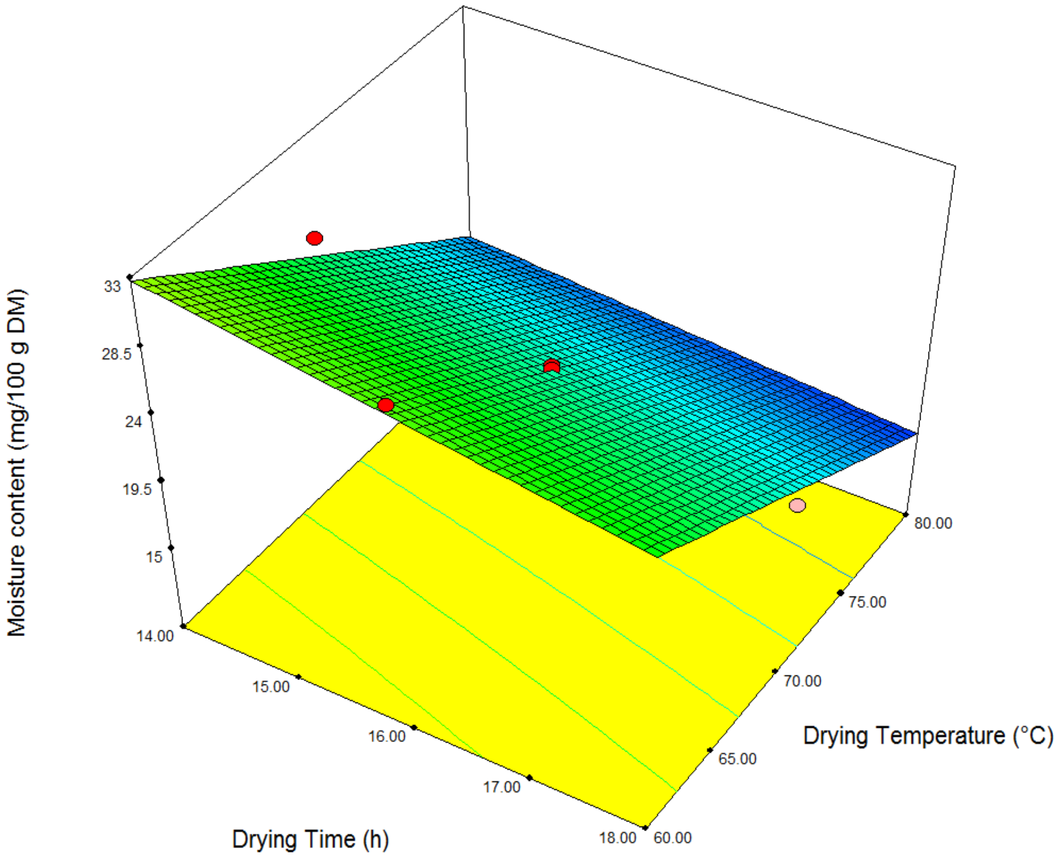
The results of the ANOVA, which are presented in Appendix L, indicate that the models developed adequately represented the actual relationships between the independent variables and responses. The F-value of the models implied that the models for qualities, such as moisture content, water activity, L*a*b*colour values, chroma, puncturing force and ascorbic acid content, were significant. The associated P-value of the models, which were used to estimate whether F was large enough to indicate statistical significance, were all lower than 0.01, indicating that the model developed and the terms were highly significant.

3.7.4 Effect of drying conditions

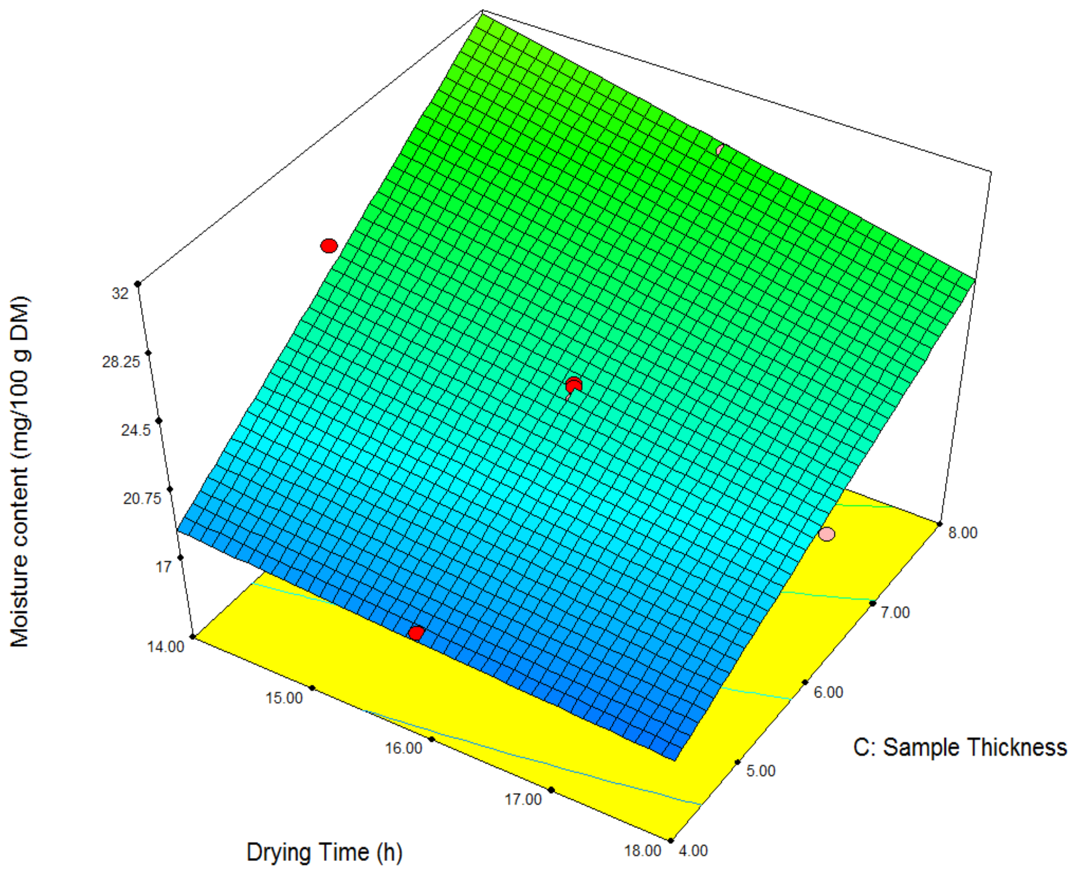
In this study, the drying conditions (drying temperature, drying time and sample thickness) were evaluated at three levels using a central composite response surface design to evaluate selected qualities of the fruit leathers. 3D response surface plots were used to represent the effect of drying conditions on the qualities of the fruit leathers. The response surface plots showed the relative effects of any two variables when the remaining variable was kept constant. The surface plots estimating the specific surface area of pigment and colour extraction versus process parameters are presented in Figures 3.12 to 3.19. The software Design-Expert (version 8.0.7.1) was used to plot the graphs.

3.7.4.1 Effects of drying time, drying temperature and sample thickness on moisture content

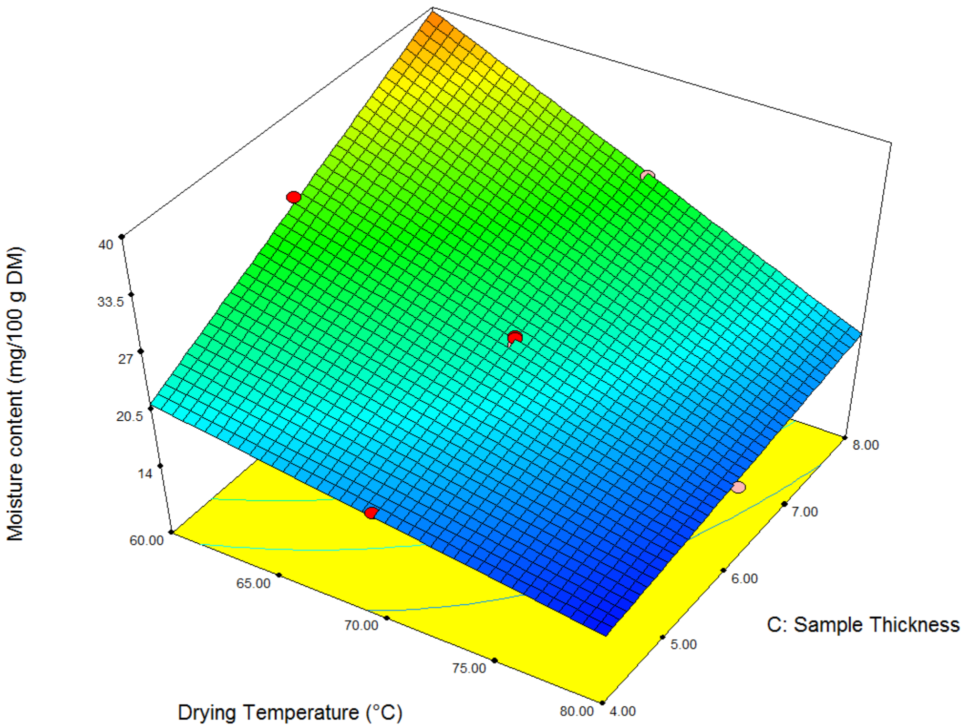
The relationship between the moisture content, drying time, drying temperature and sample thickness are shown in Figures 3.12a, b and c. The drying time, drying temperature and sample thickness are the crucial parameters which affect the moisture content of green kiwifruit-blackcurrant fruit leather. The results show that the moisture content of the products increase with increasing sample thickness and decreasing drying time and temperature.



a) Sample thickness 6 mm



b) Drying temperature 70°C

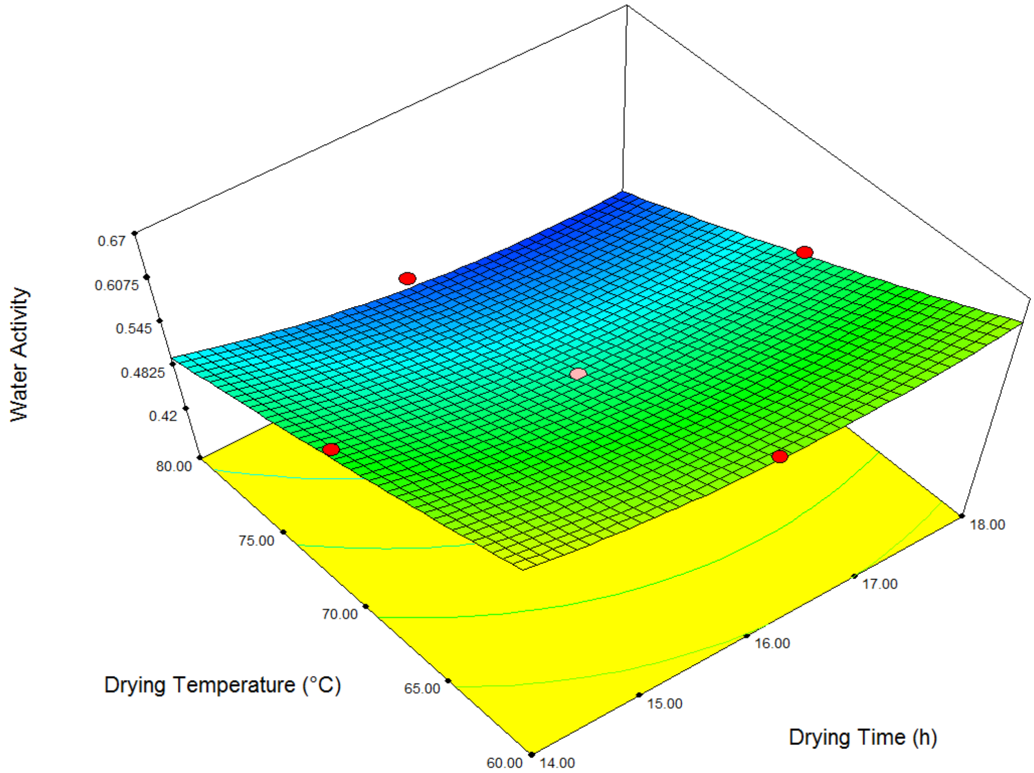


c) Drying time 16 hours

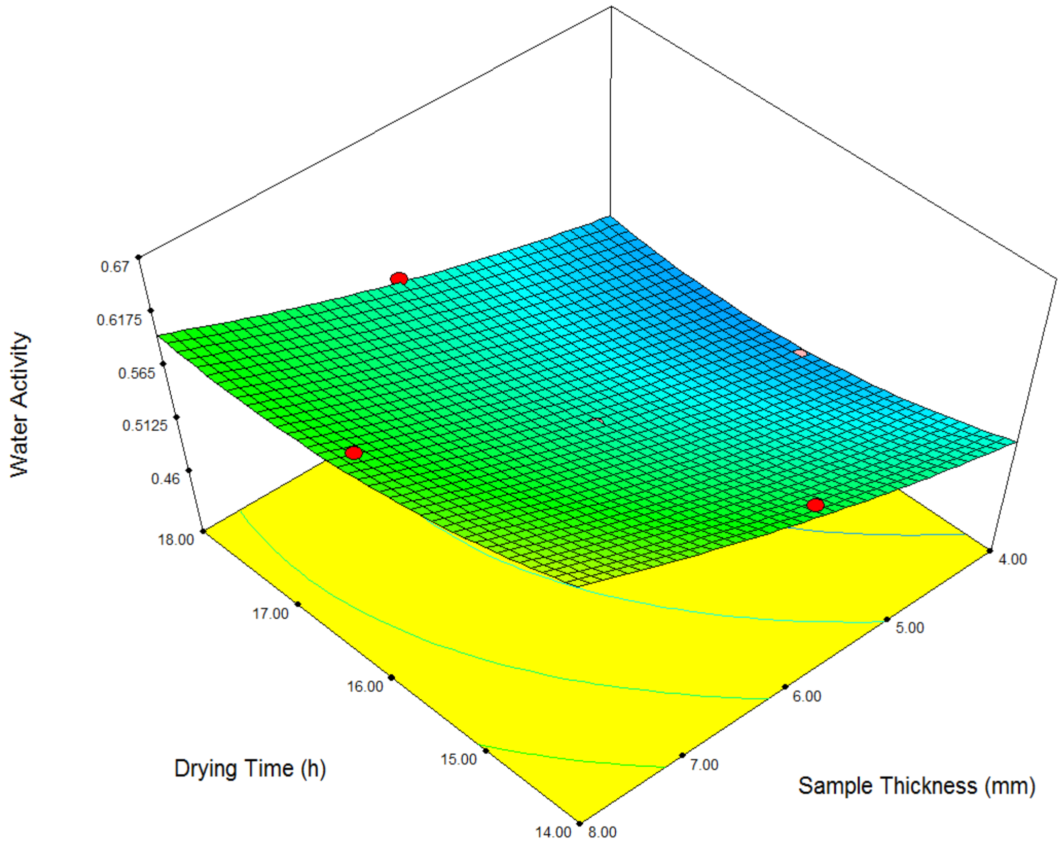
Figure 3.12 Response analysis for moisture content (g/100 g DM) of the green kiwifruit-blackcurrant fruit leather, as affected by: (a) drying time and drying temperature; (b) drying time and sample thickness; and (c) drying temperature and sample thickness, with the third factor set at the middle level

3.7.4.2 Effects of drying time, drying temperature and sample thickness on water activity

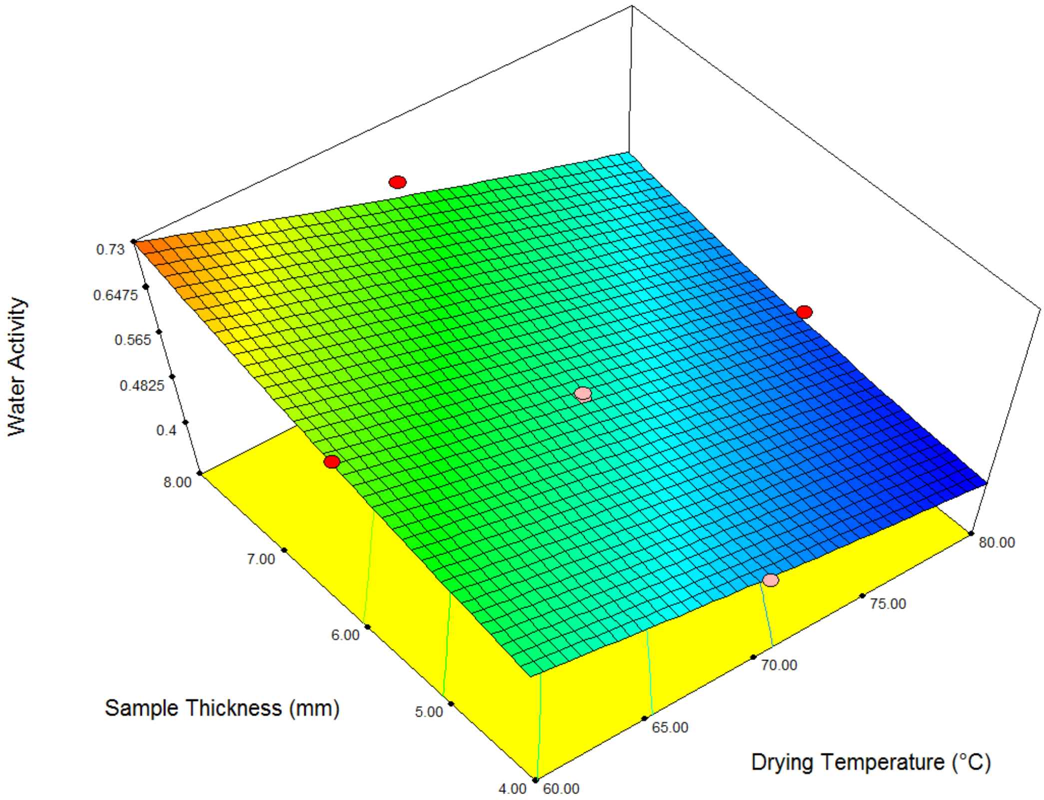
The surface plots for water activity of the green kiwifruit-blackcurrant fruit leather, as affected by drying time, drying temperature and sample thickness levels, are shown in Figures 3.13a, b and c. Drying time, drying temperature and sample thickness are significant parameters that affect the water activity of green kiwifruit-blackcurrant fruit leather. The results show that the water activity of the products increases with increasing sample thickness and decreasing drying time and temperature.



a) Sample thickness 6 mm



b) Drying temperature 70°C

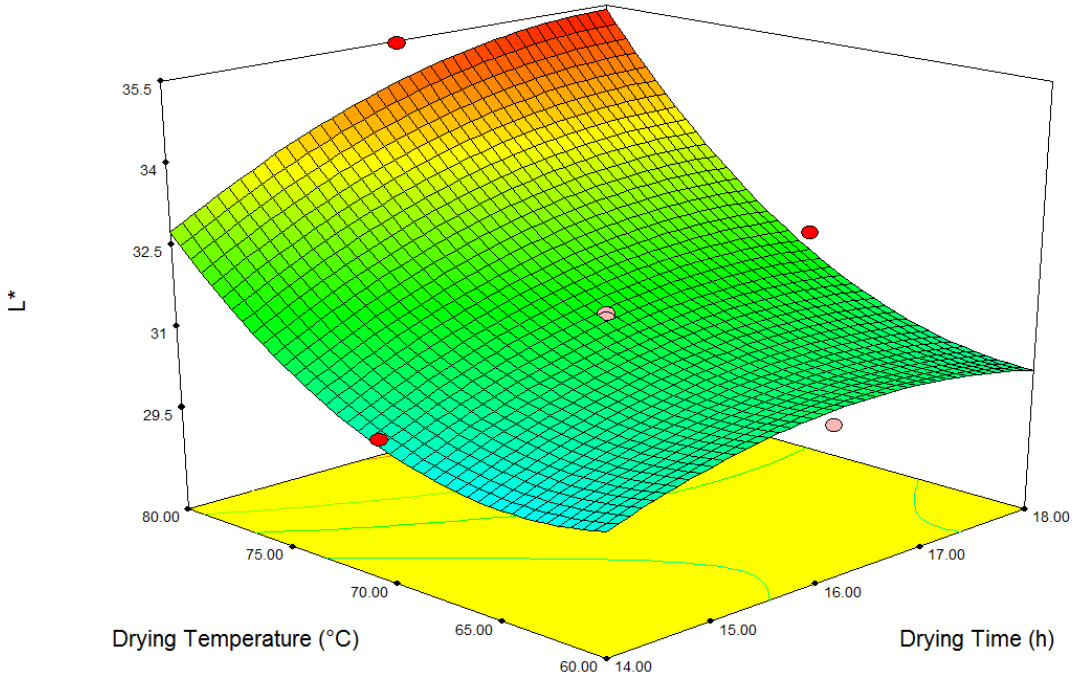


a) Drying time 16 hours

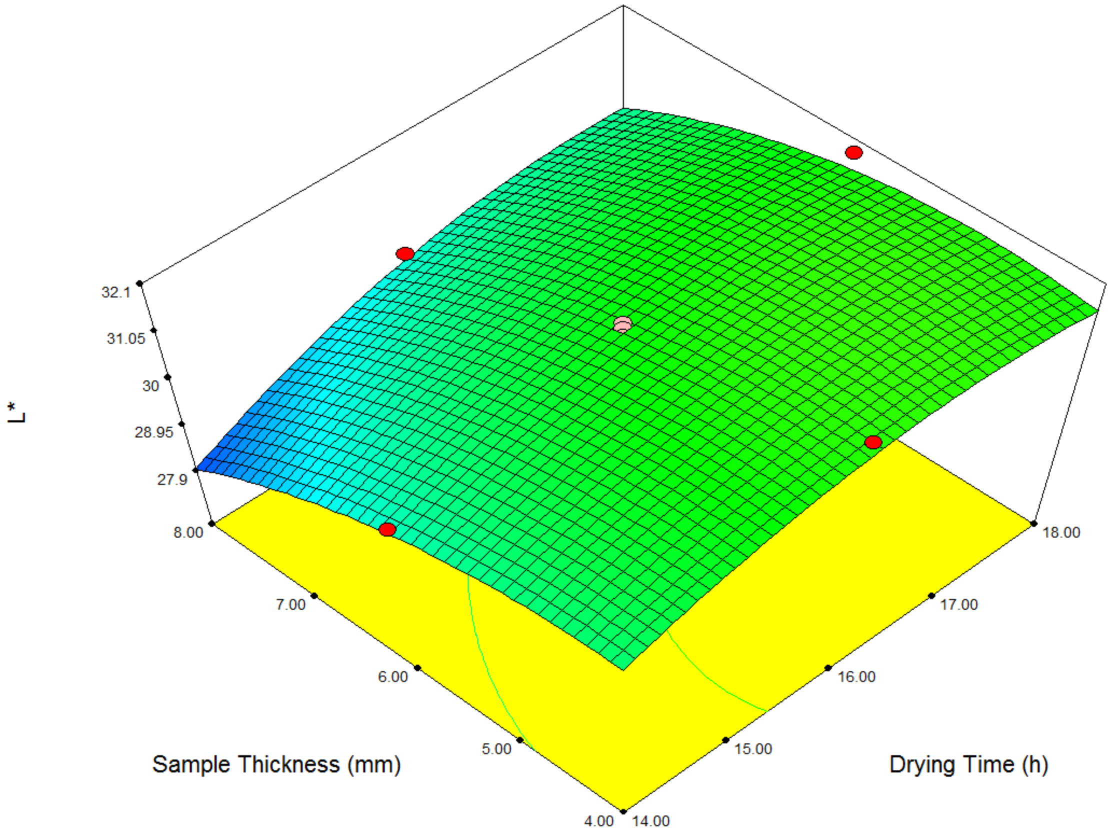
Figure 3.13 Response analysis for water activity of green kiwifruit-blackcurrant fruit leather as affected by: (a) drying time and drying temperature; (b) drying time and sample thickness; and (c) drying temperature and sample thickness, with the third factor set at the middle level

3.7.4.3 Effects of drying time, drying temperature and sample thickness on L*

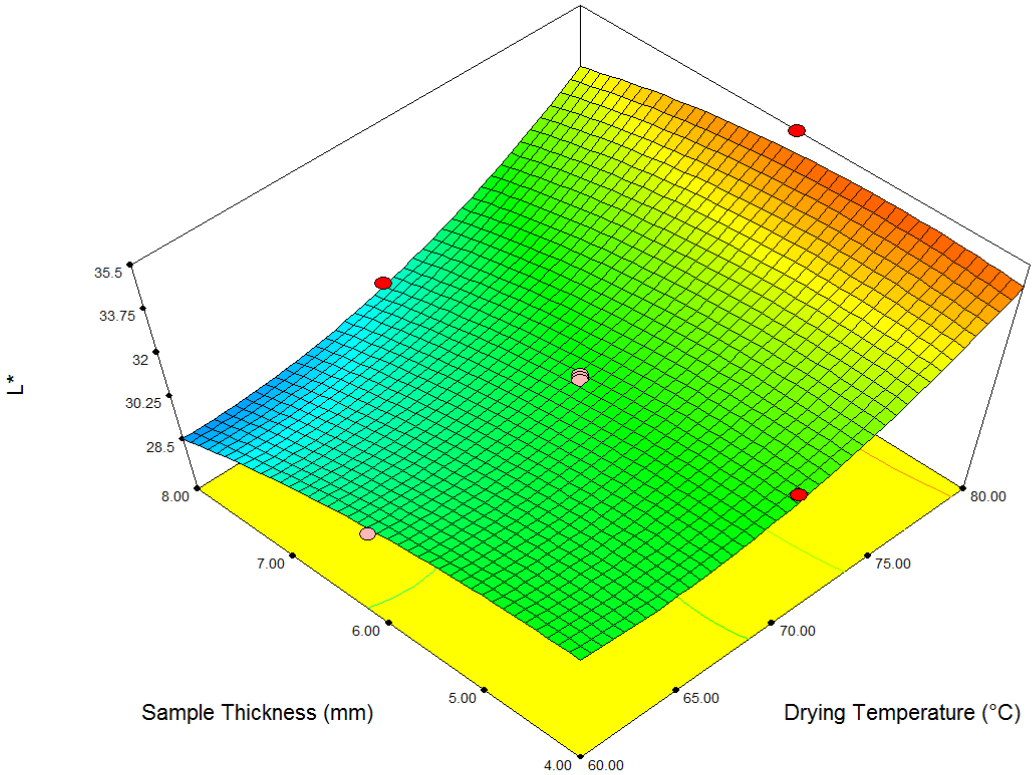
The relationship between L*, drying time, drying temperature and sample thickness are depicted in Figures 3. 14a, b and c. The results suggest that the L* of the products increases with decreasing sample thickness and increasing drying time and temperature.



a) Sample thickness 6 mm



b) Drying temperature 70°C

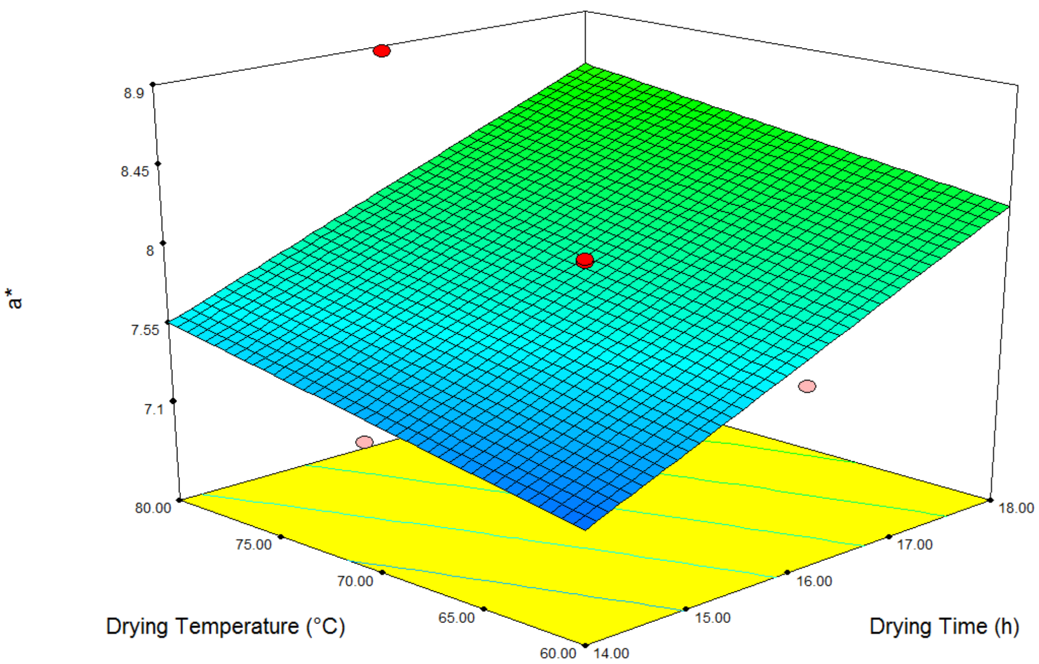


c) Drying time 16 hours

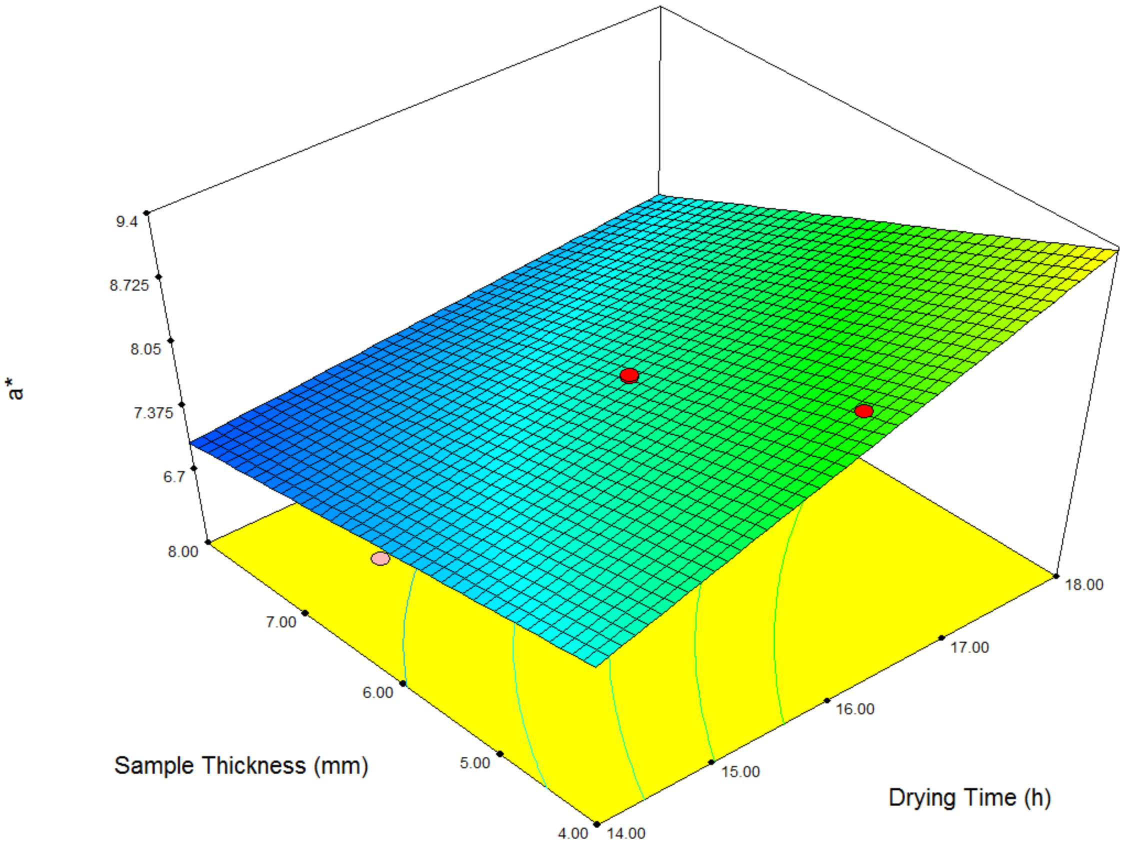
Figure 3.14 Response analysis for L* of green kiwifruit-blackcurrant fruit leather, as affectec by: (a) drying time and drying temperature; (b) drying time and sample thickness; and (b) drying temperature and sample thickness, with the third factor set at the middle level

3.7.4.4 Effects of drying time, drying temperature and sample thickness on a*

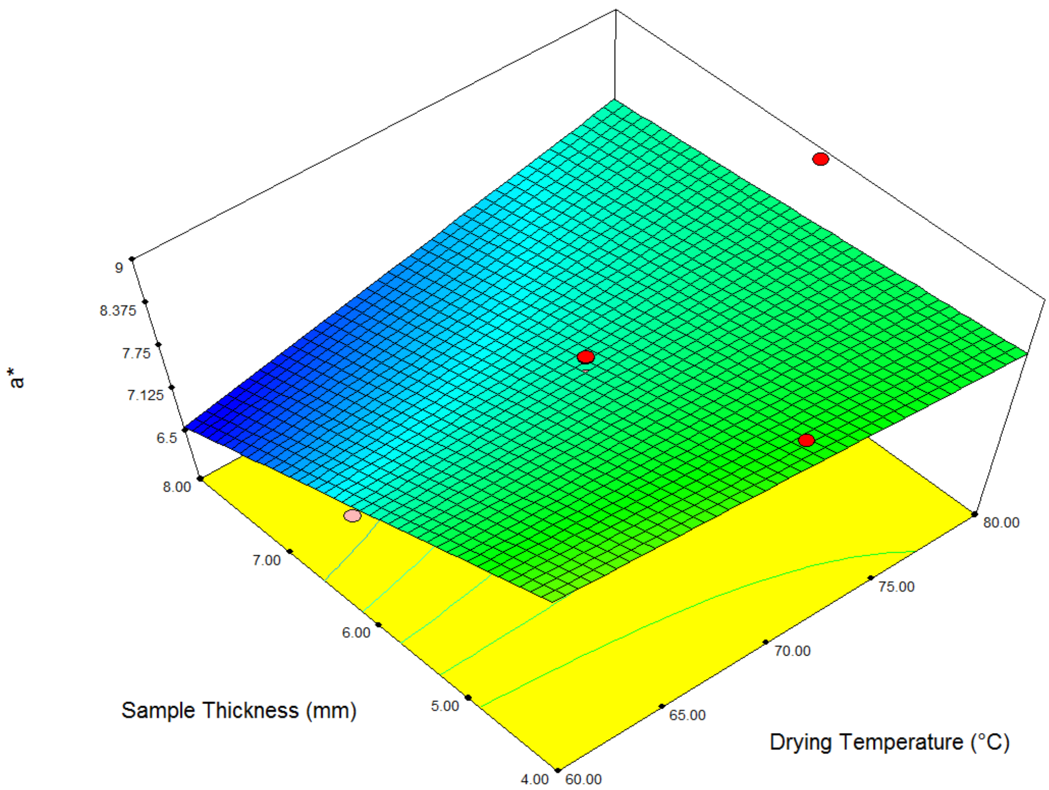
Figures 3.15a, b and c represent the relationships between a*, drying time, drying temperature and sample thickness. The results show that a* of the products increases with decreasing sample thickness and increasing drying time and temperature.



a) Sample thickness 6 mm



b) Drying temperature 70°C



c) Drying time 16 hours

Figure 3.15 Response analysis for a* of green kiwifruit-blackcurrant fruit leather, as affected by: (a) drying time and drying temperature; (b), drying time and sample thickness; and (c) drying temperature and sample thickness, with the third factor set at the middle level

3.7.4.5 Effects of dying time and drying temperature on b*

The surface plots for b* of the green kiwifruit-blackcurrant fruit leather, as affected by drying time and drying temperature, are shown in Figure 3.16. The results suggest that b* of the products increases with increasing drying time. The b* of the fruit leathers also increases with increasing drying temperature when the drying temperature is above 65°C. In contrast, the b* of the products decreases with increasing drying temperature when the drying temperature is below 65°C.

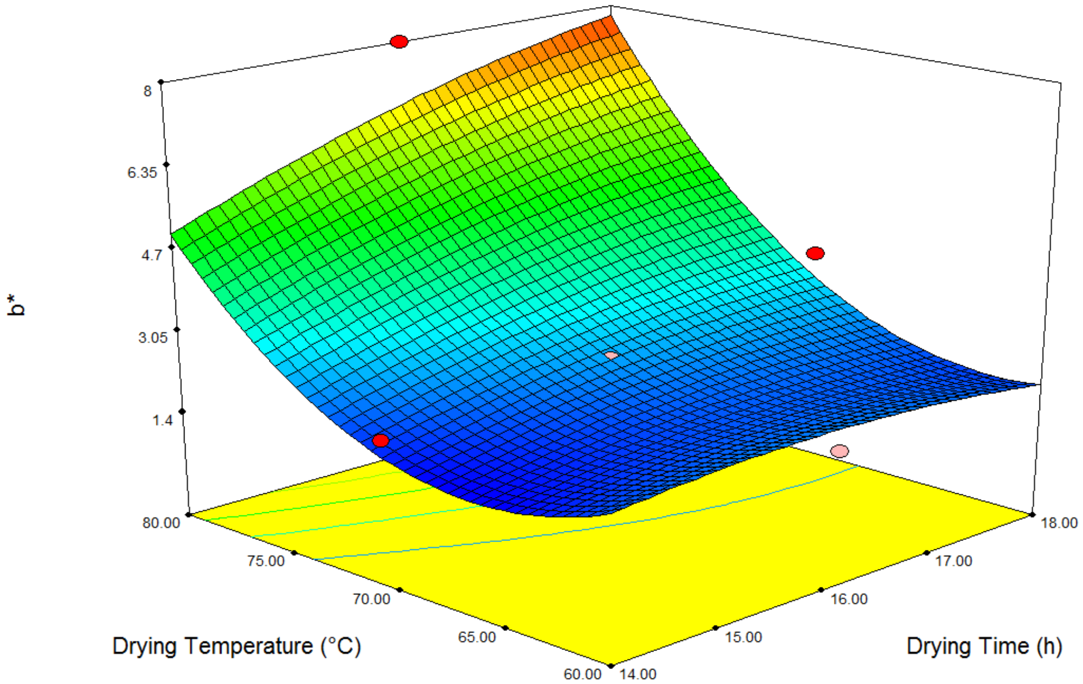
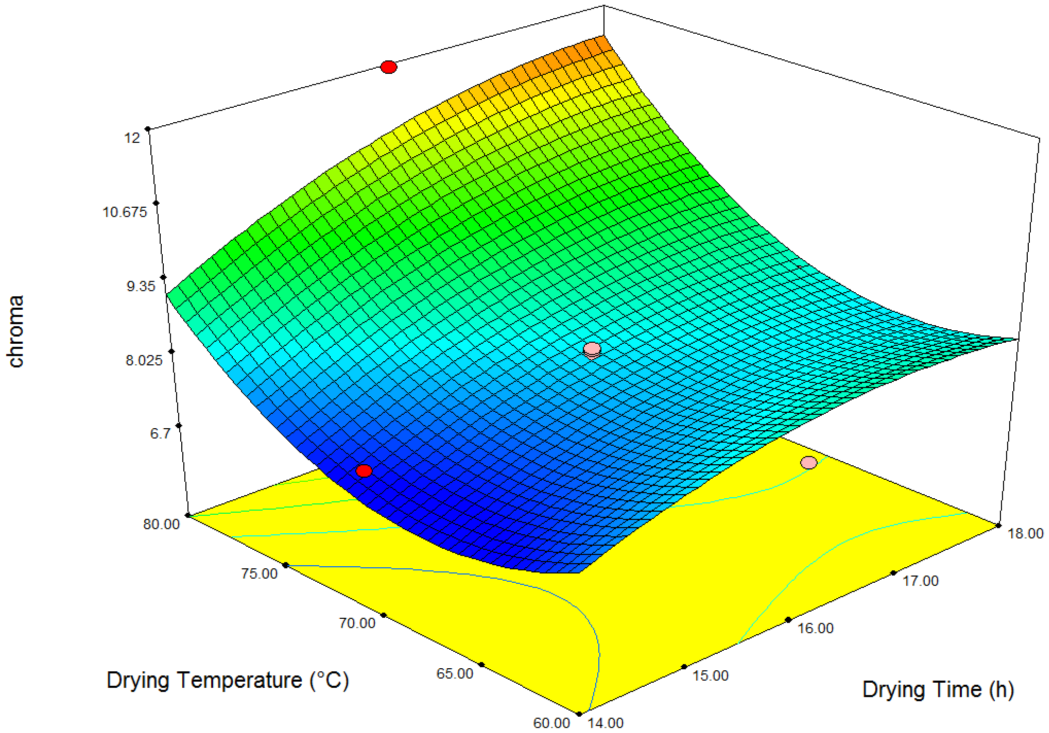


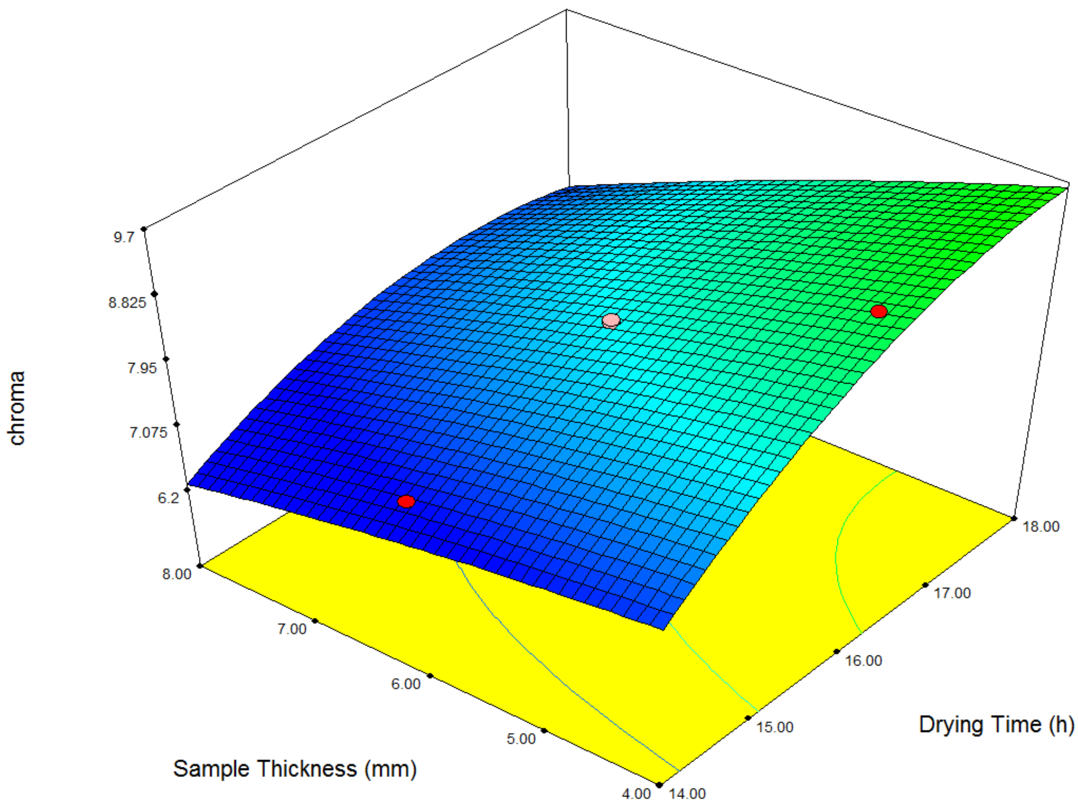
Figure 3.16 Response analysis for b* of green kiwifruit-blackcurrant fruit leather, as affected by drying time and drying temperature

3.7.4.6 Effects of drying time, drying temperature and sample thickness on chroma

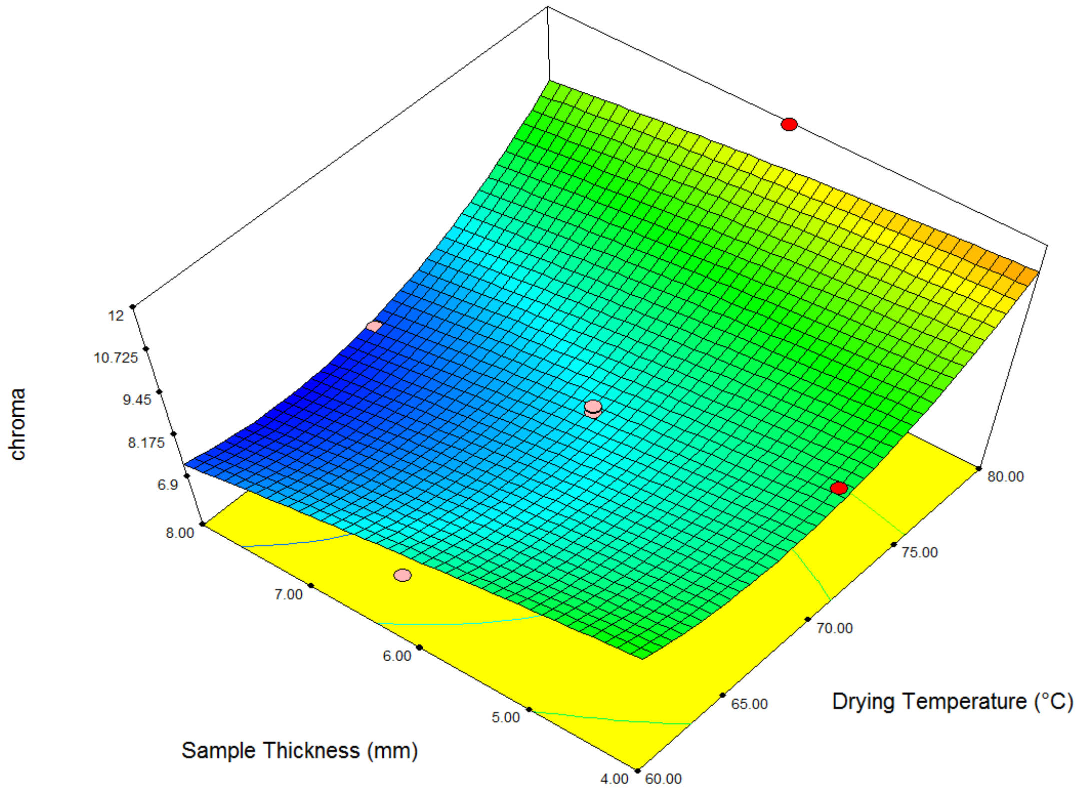
The relationships between the chroma, drying time, drying temperature and sample thickness are depicted in Figures 3.17a, b and c. The results show that chroma of the products increase with increasing drying time and decreasing sample thickness. The chroma of the green kiwifruit-blackcurrant fruit leathers increases with increasing drying temperature when the drying temperature is above 65°C. In contrast, the chroma of the products decreases with increasing drying temperature level when the drying temperature is below 65°C.



a) Sample thickness 6 mm



b) Drying temperature 70°C



c) Drying time 16 hours

Figure 3.17 Response analysis for chroma of green kiwifruit-blackcurrant fruit leather as affected by: (a) drying time and drying temperature; (b) drying time and sample thickness; and (c) drying temperature and sample thickness, with the third factor set at the middle level

3.7.4.7 Effects of drying temperature and sample thickness on puncturing force

The drying temperature and sample thickness are crucial parameters which affected the puncturing force of green kiwifruit-blackcurrant fruit leather. The results suggest that the puncturing force of the products increase with increasing drying temperature and decreasing sample thickness. The surface plots for puncturing forces of the green kiwifruit-blackcurrant fruit leather, as affected by drying temperature and sample thickness, are shown in Figure 3.18.

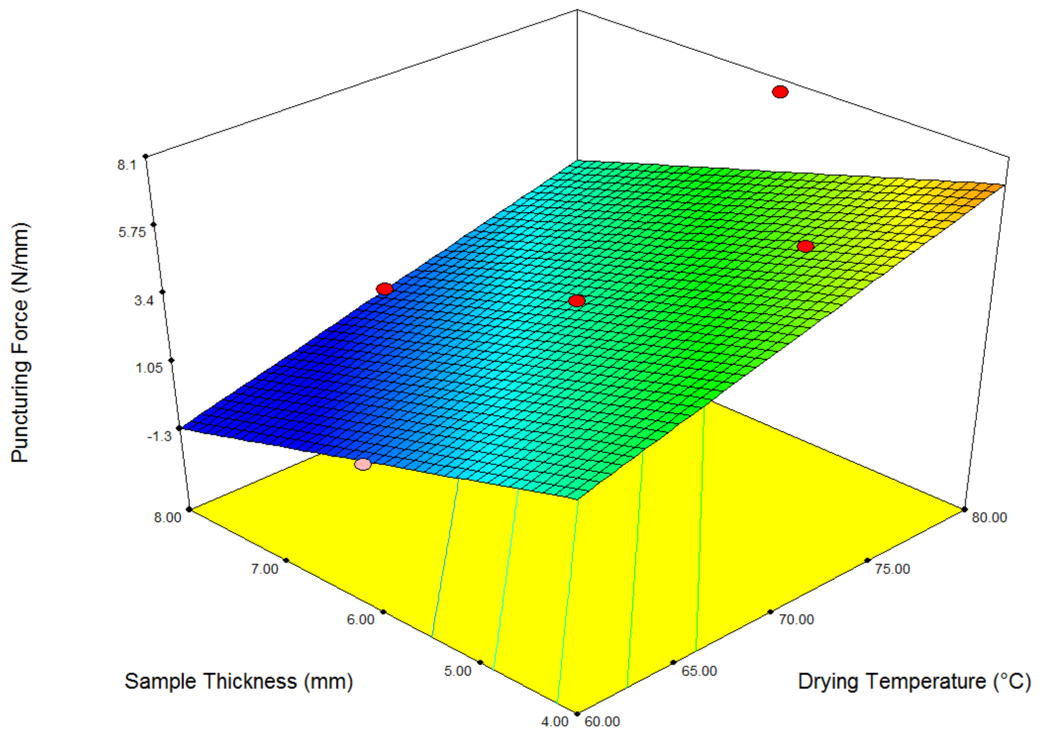


Figure 3.18 Response analysis for puncturing force of green kiwifruit-blackcurrant fruit leather, as affected by drying temperature and sample thickness

3.7.4.8 Effects of drying temperature and sample thickness on ascorbic acid content

The relationship between the ascorbic acid content, drying temperature and sample thickness are shown in Figure 3.19. The results show that ascorbic acid content of the products increase with increasing sample thickness and decreasing drying temperature.

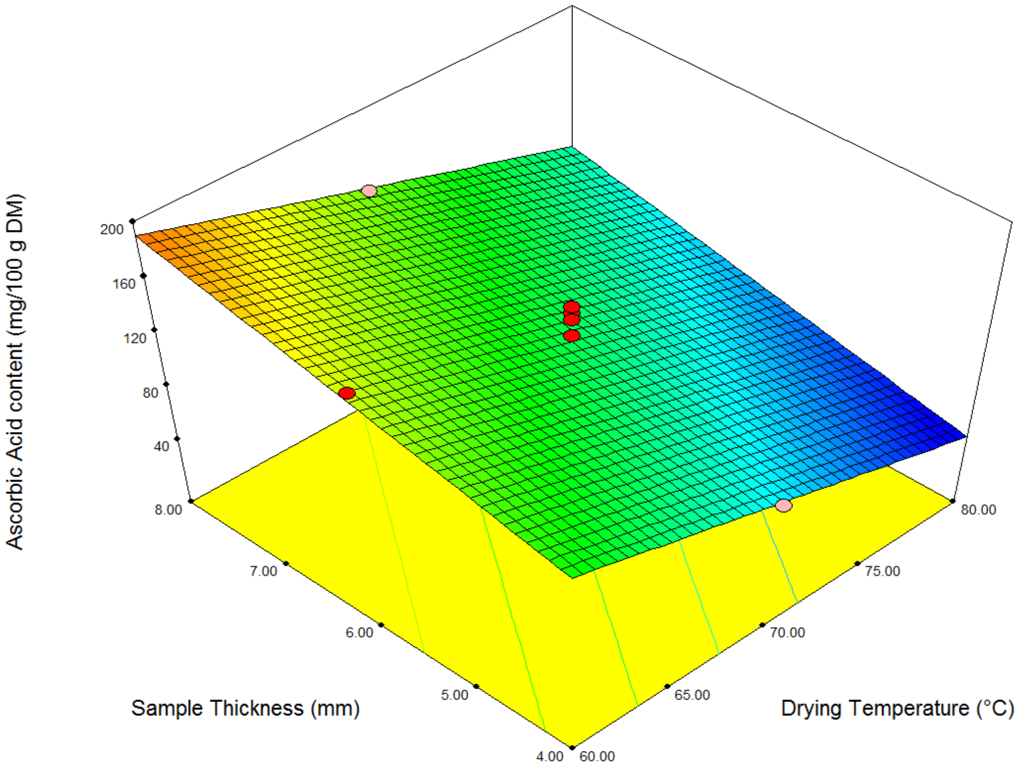


Figure 3.19 Response analysis for puncturing force of green kiwifruit-blackcurrant fruit leather, as affected by drying temperature and sample thickness

3.7.5 Optimised conditions for making green kiwifruit-blackcurrant fruit leather using central composite design

A desirability function was calculated by the programme to maximize moisture content and ascorbic acid content and minimize water activity, L*a*b* colour values, chroma and puncturing force a simultaneously in the present study. The predicted values of the characteristics at these optimum conditions were used in predicting the levels and the results shown in Table 3.14. As the Table 3.14 shown, puncturing force is over 0 just when the combinations are 14.73 hours drying time at 67.32°C with a sample thickness of 8.00 mm. So the optimum conditions for the manufacture of kiwifruit-blackcurrant fruit leather using response surface analysis in Design-Expert are: 14.73 hours drying time at 67.32°C with a sample thickness of 8.00 mm. Under these conditions the predicted responses were a moisture content of 33.72 g/100 g DM; water activity, 0.67; L*, 28.25; a*, 6.89; b*, 1.08; chroma, 6.57; puncturing force, 0.19 N/mm and ascorbic acid content 164.51 mg/100 g DM with desirability value of 0.763.

Table 3.14 Predicted values for responses of kiwifruit-blackcurrant fruit leather at optimized conditions

Drying time (h)	Drying temperature (°C)	Sample thickness (mm)	Moisture content (g/100 g DM)	Water activity	L*	a*	b*	Chroma	Puncturing force (N/mm)	Ascorbic acid content (mg/100 g DM)	desirability
14.73	67.32	8.00	33.72	0.67	28.25	6.89	1.08	6.57	0.19	164.51	0.763
15.26	66.03	8.00	34.35	0.67	28.50	6.87	1.23	6.77	-0.07	167.55	0.765
15.28	65.95	8.00	34.40	0.67	28.50	6.87	1.23	6.78	-0.09	167.74	0.765

By applying desirability function method, three solutions were obtained for the optimum conditions covering criteria with desirability values of 0.763. The individual desirability for each response and the overall desirability can be observed in Figure 3.20.

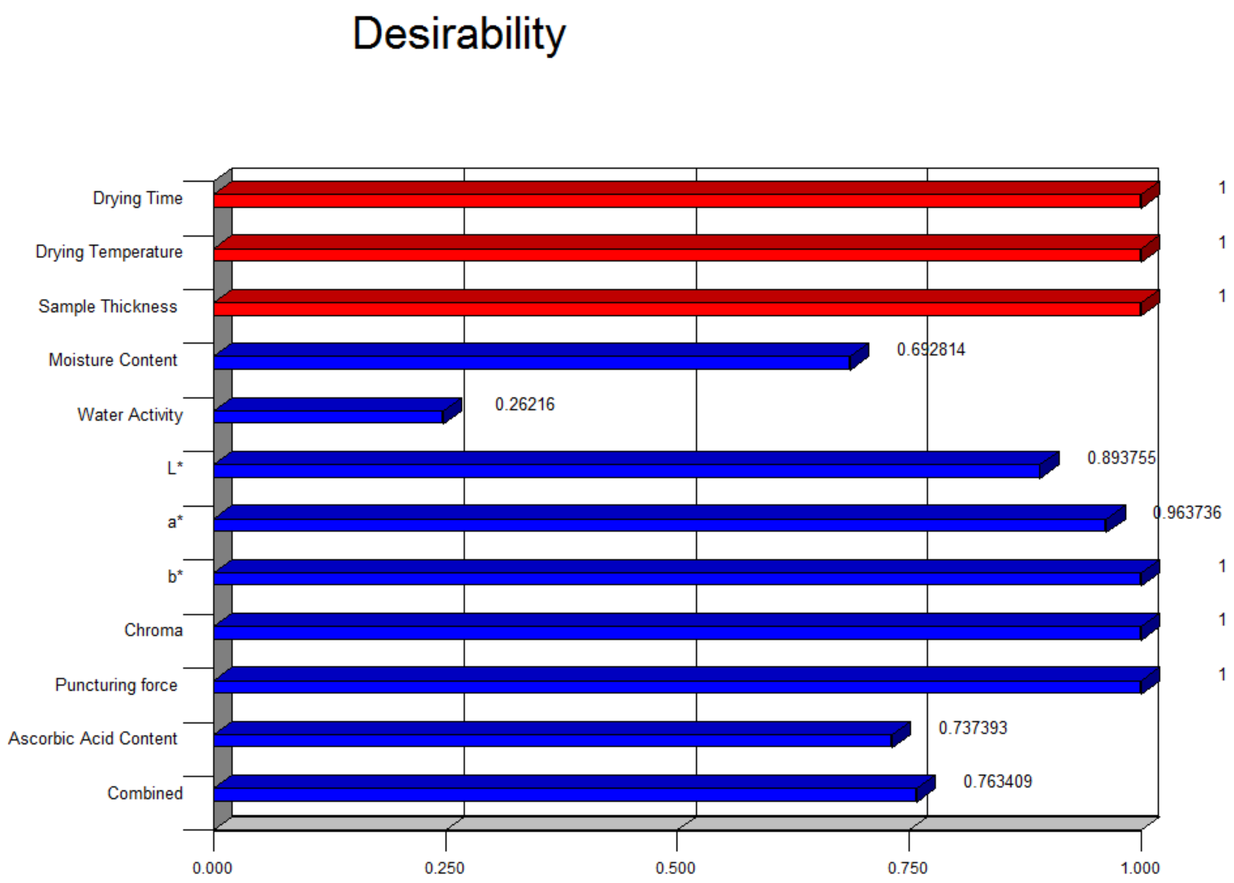


Figure 3.20 Bar graph representing individual desirability and combined desirability by a central composite design

Table 3.15 Proximate analysis and colour measurements of the final optimized product which was performed under the set of optimized combinations of 10% sugar, 8.95% blackcurrant purée and 0.03% pectin and optimized drying conditions at 14.73 hours drying time at 67.3°C with a sample thickness of 8 mm.

Proximate analysis (g/100 g DM)	
Moisture	12.82 ± 0.19
Protein	4.19 ± 0.01
Fat	2.36 ± 0.02
Water soluble carbohydrates	79.32 ± 1.89
Acid detergent fibre	7.26 ± 0.04
Neutral detergent fibre	8.03 ± 0.03
Ash	2.44 ± 0.02
L*a*b* Colour	
L*	21.32 ± 0.54
a*	10.90 ± 0.30
b*	3.60 ± 0.34
Chroma	11.49 ± 0.38
pH	3.16 ± 0.01
Titratable acidity (%TA)	4.72 ± 0.25
Water activity (a_w)	0.69 ± 0.002

To verify the precision of the model equation, triplicate proximate analysis and colour measurements of the final optimized product experiments were carried out (Table 3.15). Table 3.16 shows that the predicted value of moisture content was higher than the experimental value. The predicted value of L* was similar to the experimental result. The predicted value of L*, a*, and b* were lower than the experimental value.

Table 3.16 Predicted and experimental values for the green kiwifruit-blackcurrant fruit leather at optimized conditions

	Moisture content (g/100 g DM)	Water activity	L*	a*	b*	Chroma
Predicted values	33.72	0.67	28.25	6.89	1.08	6.57
Experimental values	12.82	0.69	21.32	10.90	3.60	11.49

Chapter 4
Discussion of response surface methodology experiments

4.1 Moisture content and water activity

The moisture content of the final dried fruit leather products ranged from 15.01 to 43.08 g/100 g DM and the water activity ranged from 0.45 to 0.76. The results showed that the moisture content and water activity increased with increasing sugar level. Jain and Nema (2007) investigated the processing of guava (*Psidium guajava* L.) pulp for leather production. Their results also suggested that the moisture content of guava leather increased significantly with increased sugar content of the guava leather.

The results obtained in this experiment suggested that the moisture content increased with increasing pectin level. Diamante *et al.* (2013a) also found that the moisture content and water activity of apple-blackcurrant fruit leathers increased with increasing pectin level, from 0 to 4%. However, these results were in contrast to research by Phimpharian *et al.* (2011) on the effect of different pectin levels (0.5, 1.0 and 1.5%) and glucose syrup (2, 4 and 6%) on the moisture content of pineapple leather. They reported that increasing pectin concentrations decreased the moisture content of the pineapple leathers. However, a previous study by Gujral and Brar (2003) found that pectin levels (1, 2 and 3%) did not affect the moisture content of mango leather. The difference might be due not only to the different pectin level used but also to the types of other ingredient (e.g. such as sugar and syrup) used. For example, Gujral *et al.* (2013) investigated moisture diffusivity during drying of pineapple and mango leather, as affected by the addition of sucrose, pectin, and maltodextrin. Their results showed that the drying rate constant of both the pineapple and mango leather was most affected by increasing the amounts of sucrose in the fruit leather, followed by maltodextrin and pectin. Huang and Hseih (2005) found that increasing the pectin concentration (from 1 to 1.5%) affected the hardness of the sample and decreased the moisture content and water activity of the pineapple fruit leathers. Water can still act as a solvent at low water content and water activity (Labuza *et al.,* 1970). Huang and Hseih (2005) included additional water in a purée of pear fruit leather. This raised the initial moisture content but did not significantly affect the water activity. This was probably because the initial differences in the water content diminished as a result of dehydration when making the fruit leather.

The moisture content of the fruit leather increased with sample thickness, while the water activity increased with sample thickness, decreasing drying time and temperature levels. This trend was also observed in studies by Maskan *et al.* (2002) and Effah-Manu *et al.* (2013). Maskan *et al.* (2002) made grape leather by hot air drying at different air temperatures (55, 65 and 75℃), sample thickness (0.71, 1.53, 2.20 and 2.86 mm) and air velocity (0.86, 1.27 and 1.82 m/s). They found that the effects of drying time, temperature and slab thickness on the moisture content of grape leather during drying were significant ($P < 0.05$) and air velocity was not ($P > 0.05$). They determined that increasing the temperature at a constant sample thickness could reduce the time required to reach the equilibrium moisture content. Lee and Hsieh (2008) investigated the thin layer drying of strawberry leather using 1.8, 2.7 and 3.6 mm sample thicknesses and drying temperatures of 50, 60, 70 and 80°C. The drying times for the strawberry leather samples to achieve the safe-storage moisture content of 12% varied from 80 to 600 minutes concerning the different drying temperatures and sample thicknesses. They found that the drying rates enhanced as the sample thickness increased from 1.8 to 3.6 mm. Effah-Manu *et al.* (2013) studied that dextrinisation of sweet potato and its effect on the physicochemical qualities of mango-sweet potato leathers. They found that the water activity values of mango-sweet potato leathers were within the range of 0.61 - 0.63, which suggested that leathers produced by the infra-red catalytic dryer in their study would not allow bacterial growth during the storage of the leather.

4.2 Colour

The outcomes indicated the L*a*b* colour values and chroma increased with increasing blackcurrant purée contents. These results were comparable with the study of Effah-Manu *et al.* (2013). They found that the L* values of mango-sweet potato leathers increased slightly (from 59.01 to 61.88) when the content of the mango purée decreased. In contrast, the L* values of green kiwifruit-blackcurrant fruit leather in this study increased with increasing blackcurrant purée contents. However, their b* values also increased significantly from 38.98 to 47.08 and the a* values increased when the content of the mango purée increased. The results showed that the leathers had a bright yellow colour. This was in agreement with the a* and b* results observed in this experiment.

The results of this experiment suggested that the chroma of the green kiwifruit-blackcurrant fruit leathers increased with increasing pectin level when the pectin level was below 3%. In contrast, the chroma of the products decreased with increasing pectin level when the pectin level was above 3%. The study by Diamante *et al.* (2013a) showed that the chroma of apple-blackcurrant fruit leathers was affected by the apple juice concentrate and pectin levels. The chroma of the products reduced with maxing pectin level. The middle apple juice concentration level gave a reduced chroma value for the products due to its quadratic effect. Nonetheless, their results had been different to the study of Phimpharian *et al.* (2011) who uncovered that the chroma of pineapple leather improved once the pectin degree increased from 0.5 to 1.5%.

The b* value of the green kiwifruit-blackcurrant fruit leathers increased with increasing drying temperature when the drying temperature was above 65°C. In contrast, the b* value of the products increased with decreasing drying temperature when the drying temperature was below 65°C; and the L* value increased with increasing drying temperature. The colour value of a* increased with increasing temperature. Chowdhury *et al.* (2011) uncovered that the chroma of jackfruit leather-based diminished with expanding temperature. The L* a* b* colour values of jackfruit leather were not significantly different at the 5% level for drying at 40 and 50°C, though the values of L* and b* had decreased significantly, along with the values of *a** increased significantly at 60 and 70°C. L* valves meant that the colour of jackfruit leather dried at 40 and 50°C was exactly the same, but the fruit leather became dark red after drying at 60 and 70°C.

The results showed that the L* value increased with increasing temperature and the colour value of a* increased with increasing drying time. The results of this experiment were similar to the study by Maskan *et al.* (2002), who determined the effect of sun drying on colour changes in grape leather. Their a* value for fruit leather increased from 3.50 to 3.74 throughout the first stage of sun drying (0 to 325 minutes) and improved slowly from 3.74 to 3.78 (325 to 1830 minutes). Their L* and b* values showed fluctuations during drying without a constant trend. They noticed a zero order a* colour change during sun drying of the fruit leather in their experiment.

4.3 Texture analysis

The results showed that the puncturing force increased with increasing pectin level and drying temperature and decreasing sample thickness level. Diamante *et al.* (2013a) determined that the puncturing force of apple-blackcurrant fruit leather lowered with escalating apple juice concentrate degree but had a decreased value at the centre pectin level (2%). Huang and Hsieh (2005) also claimed that the compressive force/hardness of pear leather lessened with increasing corn syrup level (0 to 8%) whatever the pectin degree (16 to 24%). Having said that, Phimpharian *et al.* (2011) discovered that the tensile force of pineapple leather both increased with increasing glucose and pectin levels. The main difference may well be because of heating the pineapple fruit purée mixture, the reduce pectin levels utilized from 0.5 to 1.5% or perhaps the sort of fruit utilized.

4.4 Ascorbic acid content of fresh fruit purées and fruit leathers

The results showed that the ascorbic acid content of the products increased with decreasing sugar level. Jain and Nema (2007) also found that the ascorbic acid content of the leather decreased significantly with increased sugar content.

The results of this experiment showed that the ascorbic acid content of the products increased with decreasing pectin level. Diamante *et al*. (2013a) also identified the ascorbic acid content of apple-blackcurrant fruit leather increased with increasing blackcurrant concentrate and decreasing the apple juice concentrate and pectin levels.

The ascorbic acid content of blackcurrant purée and kiwifruit were 98.14 and 91.94 mg/100 g DM when their dry matter was 13.33 and 12.69 g/100 g DM, respetively. After drying, the ascorbic acid contents of fruit leather were about 137 mg/100 g DM when their dry matter was about 75 g/100 g DM. The retention of ascorbic acid in fruit leather was about 25% of the levels in the fresh fruit and purées.

Santos and Silva (2010) showed that the loss of ascorbic acid was impacted by time, temperature and moisture content. They reported that the retention of ascorbic acid in drying processes for fruit and vegetables as long as the drying temperature remained below 42℃ . Generally, in the hot air drying method, the ascorbic acid retention was lower when the drying time was longer, the drying temperature was higher and the moisture content was lower.

Kaya *et al*. (2010) analyzed the effect of various drying conditions on the ascorbic acid content of Hayward kiwifruit (*Actinidia deliciosa* Planch). They uncovered that the degradation of ascorbic acid was strongly impacted by the drying conditions. Increasing the drying air temperature increased the degradation of ascorbic acid in the dried fruits. Conversely, the degradation of ascorbic acid was reduced by increasing the relative humidity of the drying air. The retention of ascorbic acid (mg/100 g kiwifruit) was 27.47 when the temperature was 65°C and the relative was 40%.

Erenturk *et al.* (2010) investigated that ascorbic acid degradation through air-drying of entire rosehips. Additionally they observed the variations in the ascorbic acid content through drying were affected via the drying time, drying air temperature and humidity content material. The degradation of ascorbic acid was 0.75 following drying at 70°C for 12 hours and also the degradation of ascorbic acid was 0.56 soon after drying at 50°C for 16 hours.

Effah-Manu *et al*. (2013) found that the ascorbic acid content of leathers made with 30% sweet potato was significantly different from those made from mango and 10 or 20% sweet potato ($p > 0.05$). This indicated that sweet potatoes, with an ascorbic acid value of 8.3 ± 1.7 mg/100 g WM, had increased the ascorbic acid content of the leather. Their results also showed that the shorter drying time led to higher ascorbic acid retention in these leathers.

Demarchi *et al.* (2013) analyzed the result of various temperatures (50, 60 and 70°C) within the hot-air drying rate and retention on the antioxidant capacity in apple leathers with, and without having, addition of potassium metabisulphite. The drying kinetics of apple leathers have been properly predicted by a one-term diffusive analytical remedy for airplane sheets making use of internal-external command to predict mass transfer. The mass transfer Biot amount was almost unity and also the Arrhenius dependency in the successful diffusion coefficient with temperature delivered an activation power for drying of 20.6 kJ/mol. The retention of ascorbic acid while in the apple leathers was low (6 - 16%) and lessened with escalating air temperatures even when the ensuing drying periods were shorter.

4.5 Optimization

It is very interesting that the predicted optimized values from recipes of process are different from the actual values. It is not similar to other response surface methodology studies. The predicted optimized value of these studies were usually similar to the actual experiment values (Lu *et al.,* 2014; Gadhe *et al.,* 2013; Maran *et al.,* 2015).

The low desirability value in this experiment was obtained because the calculated and predicted values of the parameters measured were so different from each other (Figure 3.20). The largest difference was seen for the water activity values (desirability value 0.262). Generally, as the number of responses increased, the desirability of the response surface methodology studies decreased. The desirability of the studies (Lu *et al.,* 2014; Gadhe *et al.,* 2013; Maran *et al.,* 2015) is over 0.9. By contrast, the desirability of this study is just 0.763. The number of the response of this study is much higher than other response surface methodology experiments. There are 8 responses in the present study, in contrast, there are only 1 or 2 responses in the other studies.

Chapter 5
Sensory evaluation

5.1 Introduction

In earlier experiments (Chapter 3) response surface methods were used to identify the optimum mixtures and processing conditions to make a green kiwifruit-blackcurrant fruit leather. The mixtures of the ingredients and processing conditions were optimized to give the highest desirability values for each of the responses that were considered to be important characteristics for a quality fruit leather product. Many of these characteristics were considered by earlier studies to make fruit leather from a range of different tropical and temperate fruits. Table 2.1 summarizes 12 different experiments where fruit leather was made from a single fruit. Seven of these experiments went on to evaluate the sensory characteristics of the final product. Table 2.2 shows the five different experiments where fruit leather were made from two different fruits, of these only two experiments went on to evaluate the product using tasting experiments. In all of these experiments the panellists were asked to record the attributes of fruit leathers such as moisture content, colour and hardness. Chan and Cavaletto (1978) found that panellists liked the lighter brown colour of papaya fruit leather. Irwandi *et al*., (1998) reported that panellists liked the lighter orange colour of durian fruit leather. Panellists also liked the lighter colour of guava, lighter yellow colour of pear, lighter red colour of gold kiwifruit and lighter yellow colour of olives and apples fruit leather (Vijayanand *et al.*, 2000; Huang and Hsieh, 2005; Vatthanakul *et al.*, 2010; Khan *et al.*, 2014). Panellists also liked a higher moisture content particularly when the moisture content ranged from 8 to 20% (Irwandi *et al.*, 1998; Safdar *et al.*, 2014; Akhtara *et al.*, 2014). In addition, panellists liked a softer texture (Vijayanand *et al.*, 2000; Huang and Hsieh, 2005) which clearly is a result of a higher moisture product. Overall, it is clear that panellists prefer a lighter coloured fruit leather that has a softer texture and a higher moisture content.

The physical responses measured in this experiment were also used in some of the experiments reviewed in chapter 2. It is important to remember, however, that a new product is designed to be eaten and sensory evaluation are the most important feature of a new product. In addition, sensory evaluation cannot be efficiently carried out without comparing the new product with other similar products. In this experiment five fruit leather products were evaluated using sensory analysis to measure the acceptability of the kiwifruit-blackcurrant fruit leather and to identify the most appreciated mixtures and processing conditions. The kiwifruit-blackcurrant fruit leader was used as the center point of the sensory evaluation with two products made with recipes above and below the optimized recipe identified earlier. In addition two fruit leather products were made from either kiwifruit or blackcurrant purée alone.

5.2 Materials

Six kilograms of firm, ripe, green kiwifruit were purchased from a local supermarket in Christchurch, New Zealand. The fruits were sorted to remove damaged or over-ripe fruits. The green kiwifruit were stored at 4°C until used in the experiments. The other three major ingredients used in the trials were sugar (Chelsea Refinery, Auckland, NZ), high methylester, slow set pectin powder (Classic AF401, Herbsteith & Fox KG., Neuenbürg, Germany) and blackcurrant purée (Barker's of Geraldine, South Canterbury, NZ). The blackcurrant purée was also stored in the chiller.

5.3 Methods

To prepare these five samples, the green kiwifruit were peeled, sliced, cored and blended into a purée, together with the sugar, blackcurrant purée and pectin following the formulations which were shown in Table 5.1. The blending process was carried out at high speed using a blender (Cascade, model CE071BR, China) for three minutes to obtain a smooth mixture. The purée was poured into an aluminium tray by using a non-stick surface and within dimensions of 300 × 200 × 6 mm. The tray which contained the fruit purée mixture is shown in Figure 5.1. The processing conditions for making fruit leathers are shown in Table 5.2.

Table 5.1 The formulation of different types of fruit leather samples for sensory evaluation

Samples	Kiwifruit purée (%)	Sugar (%)	Blackcurrant purée (%)	Pectin (%)
100% kiwifruit	89.97	10	0	0.03
100% blackcurrant	0	10	89.97	0.03
Optimised recipe	81.02	10	8.95	0.03
Below optimised recipe	81.02	10	8.95	0.00
Above optimised recipe	96.94	0	3	0.06

Figure 5.1 The tray which contained the fruit purée mixture

Table 5.2 Processing conditions of the different types of fruit leather samples for sensory evaluation

Samples	Time (hours)	Mean temperature (°C)	Mean thickness (mm)
100% kiwifruit	14.73	67.32	8.00
100% blackcurrant	14.73	67.32	8.00
Optimised recipe	14.73	67.32	8.00
Below optimised recipe	14	67.32	6.00
Above optimised recipe	16	67.32	10.00

A consumer acceptability sensory trial was conducted at Lincoln University in the Sensory Suite (RFH Building). Panellists comprised 52 volunteers who were students and staff from Lincoln University. Each panellist was asked to taste five samples (one for each of the five different treatments) of previously prepared fruit leathers (Figure 5.2). The sensory evaluations were carried out in sensory testing booths (Figures 5.3 and 5.4). Samples were labelled using 3-digit random numbers and presented on an identical white plastic tray to each panellist in a random order. Each panellist was encouraged to eat a small piece of plain cracker and clean their palate with tap water between samples.

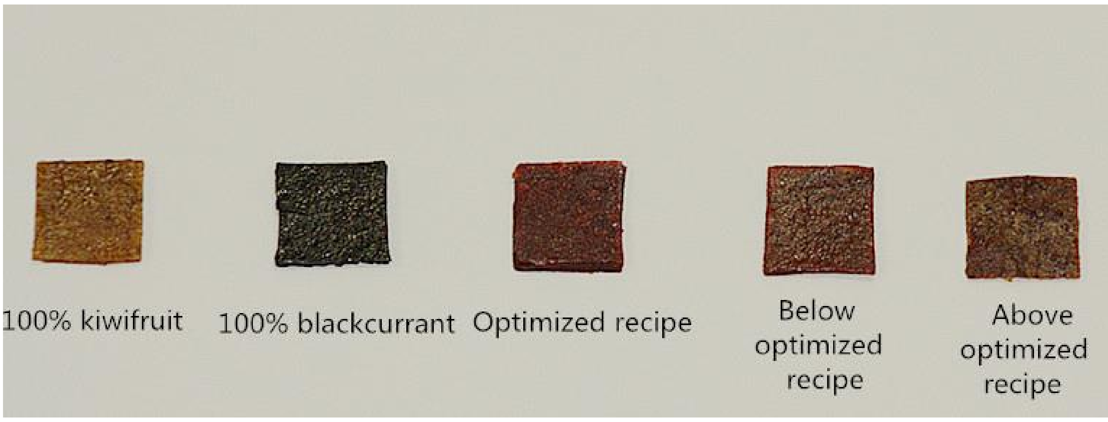


Figure 5.2 Five types of previously prepared fruit leathers used for the sensory evaluation

Figure 5.3 Booth presentation for the consumer-type sensory trial (a)

Figure 5.4 Booth presentation for the consumer-type sensory trial (b)

Each panellist was asked six quality attribute questions for each sample. The attributes selected for the kiwifruit-blackcurrant fruit leathers were overall liking and colour, flavour, sourness, sweetness and texture of the sample. The scores and attributes of fruit leather are shown in Table 5.3. The data were analysed using a one way ANOVA analysis using IBM SPSS Statistics version 22 to determine any statistical differences between the five different types of fruit leather. The level of confidence was 95%. A total of 52 responses were obtained for statistical analysis of the organoleptic assessments.

Table 5.3 Scores and attributes of fruit leather

Score	Overall liking	Colour	Flavour	Sourness	Sweetness	Texture
1	Dislike extremely	too light	too weak	bland	bland	too soft
2	Dislike very much	very light	very weak	little sour	little sweet	very soft
3	Dislike slightly	slightly light	slightly weak	a bit sour	a bit sweet	slightly soft
4	Neither like nor dislike	Just about right	Just about right	Just about right	Just about right	Just about right
5	Like slightly	slightly dark	slightly strong	slightly sour	slightly sweet	slightly hard
6	Like very much	very dark	very strong	very sour	very sweet	very hard
7	Like extremely	too dark	too strong	too sour	too sweet	too hard

5.4 Results

Table 5.4 shows the mean scores of overall liking, colour, flavour, sourness, sweetness and texture for all fruit leathers. For the overall preference for the overall liking, the mean scores were between 2.7 and 4.9. The highest score for the overall liking attribute was 4.9 for the ‘optimised recipe’. The overall liking score for the ‘below optimised recipe’ was also higher than the other types. The highest means for overall liking of the different types fell between ‘like slightly’ and ‘neither like nor dislike’.

For colour, all samples received mean scores between 3.3 and 6.2. The colour of ‘100% blackcurrant’ was considered the darkest by the panellists, whereas the colour of ‘100% kiwifruit’ was considered as the lightest. The score of the ‘optimised recipe’ was the median of the five types.

The mean score for flavour ranged from 3.3 to 4.8. ‘100% blackcurrant’ had the highest score of 4.8 ± 0.2 for flavour. The sensory results showed the fruit leather made using the ‘100% blackcurrant’ recipe had the most preferred flavour compared to the other types. The score of the ‘optimised recipe’ (3.8 ± 0.1) was just below the ‘100% blackcurrant’ but higher than the other types. The mean score of sweetness was 3.34 ± 0.08. The below optimised recipe’ had the highest score of 3.8 ± 0.2 for sweetness. The score of the ‘optimised recipe’ (3.8 ± 0.1) was the same as for the ‘below optimised recipe’ and higher than the other types.

For the overall preference of sourness, the mean scores for fruit leather were between 4.4 and 5.4. For sourness, the highest score for the sourness attribute was 5.4 for '100% blackcurrant'. In contrast, the 'optimised recipe' had the lowest score.

The mean score for texture ranged from 4.0 to 5.8. The score for the texture of the 'optimised recipe' was the lowest of the five types means the texture of the 'optimised recipe' was the softest of the five samples.

Table 5.4 Mean preference scores (± SE) for overall liking, colour, flavour, sourness, sweetness and texture for different types of fruit leathers

Fruit leather	Overall liking	Colour	Flavour	Sourness	Sweetness	Texture
100% kiwifruit	4.3 ± 0.2^{b}	3.3 ± 0.2^{c}	3.5 ± 0.2^{b}	5.0 ± 0.2^{a}	3.5 ± 0.2^{a}	4.2 ± 0.1^{b}
100% blackcurrant	2.7 ± 0.2^{c}	6.2 ± 0.2^{a}	4.8 ± 0.2^{a}	5.4 ± 0.2^{a}	2.8 ± 0.2^{b}	4.5 ± 0.2^{b}
Optimised recipe	4.9 ± 0.2^{a}	4.2 ± 0.1^{b}	3.8 ± 0.1^{b}	4.4 ± 0.1^{b}	3.8 ± 0.1^{a}	4.0 ± 0.1^{b}
Below optimised recipe	4.7 ± 0.2^{ab}	4.0 ± 0.1^{b}	3.7 ± 0.1^{b}	4.4 ± 0.1^{b}	3.8 ± 0.2^{a}	4.3 ± 0.1^{b}
Above optimised recipe	2.8 ± 0.2^{c}	3.4 ± 0.2^{c}	3.3 ± 0.2^{b}	4.6 ± 0.2^{b}	2.9 ± 0.2^{b}	5.8 ± 0.2^{a}

Mean values within a column with the same superscript are not significantly different ($P < 0.05$) using a LSD test.

In brief, the 'optimised recipe' fruit leather was the most preferred. It was most liked overall by the panellists. It had modest colour, texture, flavour and sweetness. The sourness score of the 'optimised recipe' fruit leather was the lowest.

5.5 Disscusion

The overall liking score of 'optimised recipe' sample was highest which has the middle records of colour, flavor. The sourness of 'optimised recipe' was weakest. Its sweetness was sweetest and its texture was softest. As Table 2.1 and 2.2 shown, higher moisture content, lighter colour and softer texture were more liked by the panellists in the sensory test of other studies.

The sensory evaluation results fitted very well to the response surface methodology results. For example, the 'above optimised recipe' sample had no sugar added and had the highest pectin content. The response surface methodology results showed that when the sugar was decreased in the mixes, the moisture content and water activity also decreased, and the puncturing force increased with increasing pectin level. The texture score of the 'optimised recipe' sample was the lowest of the five samples. The score of sweetness and overall liking of the 'Below optimised recipe' sample were the second lowest. Phimpharian *et al.* (2011) also found that increasing pectin concentrations negatively affected the toughness acceptability.

The texture of the 'optimised recipe' sample had the lowest score indirecting softness and its overall liking was the highest. This was similar to the study of Vatthanakul *et al.* (2010). They found that Thai consumers wanted kiwifruit leathers that were more fruit flavoured and less hard. The hardness scores associated with the results of puncturing force. As the response surface methodology results have shown, the puncturing force of fruit leather increased with increasing pectin level, drying temperature and decreasing sample thickness. Huang and Hsieh (2005) also found that their sensory panellists liked the softer products.

The sweetness score of the 'optimised recipe' and the 'below optimised recipe' samples were the same and higher than other samples which contained the highest sugar content. Sharma *et al.* (2013) selected the best recipe for wild apricot fruit leather on the basis of sensory evaluation. Their sensory evaluation results indicated that a very good apricot fruit leather can be prepared by using wild apricot pulp containing 60% sugar. The lower score obtained by the fruit leather prepared using 40 and 50% sugar was probably due to the high acidity of the product.

Overall, the 'optimised recipe' sample which had modest colour, texture, flavour and sweetness and the lowest sourness was most liked by the panellists in the sensory evaluation. It also means the optimum mixtures and processing conditions of the green kiwifruit-blackcurrant fruit leather identified by the response surface method was preferred by the panellists.

Chapter 6
Conclusions

In this experiment response surface methodology was used successfully to gain an understanding of the ingredient combinations of sugar, blackcurrant and kiwifruit purée and pectin, under different conditions of drying time, drying temperature and sample thickness, on the important physicochemical qualities of moisture content, water activity, colour, texture and ascorbic acid content of green kiwifruit-blackcurrant fruit leather**.** This process led to an efficient approach to creating a green kiwifruit-blackcurrant fruit leather food product that had good qualities and was liked by people in a sensory evaluation.

It can be concluded from this study that the ingredient combinations and drying conditions influence a number of physicochemical qualities and it showed how they influenced them. Sugar content affects moisture content, water activity and ascorbic acid content of fruit leather. Blackcurrant purée affected water activity and the L*a*b* colour values and chroma. Pectin content affected moisture content, a* colour value, texture and ascorbic acid content. Drying temperature affected all the physicochemical qualities of the final product. Sample thickness also affected all the physicochemical qualities of the final dried product. Drying time affected moisture content, water activity and L*a*b* colour values and chroma.

Sensory evaluation is a very important step in the development of a new food product. On the basis of sensory evaluation, the 'optimised recipe' for green kiwifruit-blackcurrant fruit leather was ranked highest and most preferred by the panellists. It had modest colour, texture, flavour and sweetness. These results showed that response surface methodology is a very good technique to understand and manage the physical parameters of the new food product. Further studies should be carried out to use response surface methodology to investigate the use of the desirability function and to investigate the relationships between predicted optimized and actual experimental values. Setting closer upper and lower limits of the parameters and the desired response values might lead to a more accurate final product specification.

Overall, the development of this product was very successful and the next step in the development of a successful commercial product would be evaluation of the shelf-life of the optimised product. Further studies are required investigate the possibility of reducing the moisture content of the optimized product without overheating the fruit leather and destroying the important features of this interesting product.

Appendices

Appendix A

Raw data for the moisture content (% wet basis and % dry basis) of different green kiwifruit-black currant fruit leather samples from Box-Behnken design experiments

Sample	Mean moisture content (% wet basis)	Mean moisture content (% dry basis)
1	20.30	25.47
2	19.71	24.55
3	19.23	23.81
4	20.87	26.37
5	15.39	18.19
6	17.84	21.71
7	20.72	26.14
8	21.01	26.60
9	16.61	19.92
10	16.60	19.90
11	20.58	25.91
12	19.43	24.12
13	18.46	22.64
14	19.21	23.78
15	19.01	23.47
16	18.79	23.14

Appendix B

Raw data for the water activity (a_w) of different green kiwifruit-black currant fruit leather samples from Box-Behnken design experiments

Sample	Replicate 1	Replicate 2	Replicate 3	Mean a_w
1	0.49	0.50	0.51	0.5
2	0.75	0.77	0.77	0.76
3	0.61	0.60	0.58	0.60
4	0.62	0.62	0.62	0.62
5	0.59	0.59	0.58	0.59
6	0.61	0.61	0.60	0.61
7	0.58	0.58	0.57	0.58
8	0.58	0.57	0.57	0.58
9	0.67	0.68	0.65	0.67
10	0.64	0.64	0.64	0.64
11	0.59	0.58	0.57	0.58
12	0.56	0.55	0.55	0.56
13	0.61	0.62	0.61	0.61
14	0.61	0.60	0.61	0.61
15	0.59	0.58	0.58	0.58
16	0.59	0.58	0.58	0.58

Appendix C

Raw data for the L*a*b* colour values, chroma of different green kiwifruit-black currant fruit leather samples from Box-Behnken design experiments

Sample	Replicate	L*	a*	b*	Chroma
1	1	32.67	10.45	6.03	12.06
	2	32.63	10.06	5.73	11.58
	3	32.38	9.88	5.43	11.27
	4	36.17	8.73	8.31	12.25
	5	36.02	8.50	7.75	11.50
2	1	31.74	8.91	5.70	10.58
	2	34.07	9.75	5.91	11.40
	3	33.71	9.08	5.61	10.67
	4	34.28	10.62	6.90	12.66
	5	34.30	10.07	6.76	12.13
3	1	29.43	8.34	1.73	8.52
	2	32.94	7.95	4.41	9.09
	3	28.37	7.68	1.29	7.79
	4	28.65	7.60	1.51	7.75
	5	33.33	7.71	4.49	8.92
4	1	29.87	8.25	1.73	8.43
	2	32.16	8.30	3.29	8.93
	3	30.58	7.07	1.17	7.17
	4	29.24	6.56	1.22	6.67
	5	31.13	8.35	3.84	9.19
5	1	30.38	7.33	2.20	7.65
	2	30.84	7.98	2.85	8.47
	3	30.31	6.98	1.94	7.24
	4	30.62	7.29	2.03	7.56
	5	30.14	8.70	2.89	9.17
6	1	30.27	6.53	1.51	6.70
	2	30.46	7.29	1.68	7.48
	3	30.27	7.90	1.82	8.11
	4	30.93	8.94	2.07	9.18
	5	30.25	7.31	1.67	7.50

Raw data for the L*a*b* colour values, chroma of different green kiwifruit-black currant fruit leather samples from Box-Behnken design experiments

Sample	Replicate	L*	a*	b*	Chroma
7	1	30.11	9.57	3.53	10.20
	2	30.22	8.53	4.18	9.50
	3	30.07	9.36	3.55	10.01
	4	30.74	10.05	3.37	10.60
	5	30.22	10.17	3.27	10.68
8	1	32.08	9.16	2.87	9.60
	2	30.83	8.44	2.70	8.86
	3	30.65	8.88	2.52	9.23
	4	31.21	9.73	3.20	10.24
	5	31.19	11.16	3.49	11.69
9	1	31.72	8.10	4.13	9.09
	2	31.99	8.27	4.15	9.25
	3	31.41	7.59	3.98	8.57
	4	30.80	7.70	4.12	8.73
	5	31.35	7.67	3.93	8.62
10	1	29.43	6.28	0.83	6.33
	2	29.26	5.82	0.63	5.85
	3	29.19	6.96	0.89	7.02
	4	29.45	5.97	0.83	6.03
	5	29.65	5.54	0.68	5.58
11	1	31.60	8.88	4.66	10.03
	2	31.14	8.01	4.48	9.18
	3	31.19	8.07	4.83	9.40
	4	31.58	8.49	4.81	9.76
	5	31.64	8.40	4.71	9.63
12	1	29.38	8.15	1.69	8.32
	2	29.27	8.08	1.99	8.32
	3	30.32	8.12	1.73	8.30
	4	30.38	8.22	1.88	8.43
	5	29.86	7.70	1.72	7.89

Raw data for the L*a*b* colour values, chroma of different green kiwifruit-black currant fruit leather samples from Box-Behnken design experiments

Sample	Replicate	L*	a*	b*	Chroma
13	1	31.67	9.62	2.80	10.02
	2	31.58	9.90	3.10	10.37
	3	31.83	9.87	3.20	10.38
	4	32.02	9.54	3.00	10.00
	5	31.49	10.07	3.22	10.57
14	1	30.88	8.70	2.94	9.18
	2	30.31	8.14	2.87	8.63
	3	31.56	9.05	3.06	9.55
	4	31.45	10.24	3.36	10.78
	5	32.46	10.37	3.43	10.92
15	1	31.10	9.08	3.01	9.57
	2	31.75	9.39	2.99	9.85
	3	31.67	9.18	2.83	9.61
	4	31.17	8.38	2.79	8.83
	5	31.69	9.38	2.82	9.79
16	1	31.89	9.57	3.35	10.14
	2	31.66	8.46	2.84	8.92
	3	32.09	8.45	2.92	8.94
	4	32.44	8.61	2.68	9.02
	5	32.04	7.94	2.75	8.40

Appendix D

The mean results of puncturing force of different green kiwifruit-black currant fruit leather samples from Box-Behnken design experiments

Sample	Mean thickness (mm)	Mean puncturing force (kg)	Mean puncturing force (kg/mm)	Mean puncturing force (N/mm)
1	2.30	2.07	0.90	8.83
2	2.90	1.12	0.39	3.82
3	2.39	2.34	0.98	9.61
4	3.03	0.70	0.23	2.26
5	1.83	0.39	0.21	2.06
6	2.37	0.15	0.06	0.61
7	2.95	2.36	0.80	7.85
8	3.14	1.40	0.45	4.41
9	2.12	0.20	0.09	0.91
10	2.21	0.30	0.14	1.37
11	2.83	2.18	0.77	7.55
12	3.06	2.21	0.72	7.06
13	2.35	1.30	0.55	5.39
14	2.34	1.18	0.51	5.00
15	2.35	1.23	0.52	5.10
16	2.19	1.68	0.77	7.55

Appendix E

The mean ascorbic acid content of different green kiwifruit-black currant fruit leather samples from Box-Behnken design vitamin C experiments

Sample	Mean volume of DPIP (ml)	Mean weight of sample (g)	Mean ascorbic acid content (mg/100 g DM)
1	9.21	1.04	172.05
2	5.26	1.01	91.32
3	5.28	0.49	187.92
4	4.66	0.74	111.72
5	7.50	0.77	163.43
6	5.40	0.71	131.90
7	4.46	0.71	112.07
8	4.09	0.74	100.18
9	7.56	0.74	173.84
10	7.45	0.71	162.74
11	5.15	0.71	112.62
12	4.84	0.71	105.74
13	6.42	0.71	140.21
14	5.58	0.71	121.92
15	5.75	0.71	125.50
16	6.07	0.71	132.69

Appendix F

Raw data for the moisture content (% wet basis and % dry basis) of different green kiwifruit-black currant fruit leather samples from central composite design experiments

Sample	Mean moisture content (% wet basis)	Mean moisture content (% dry basis)
1	17.82	21.68
2	17.32	20.95
3	13.05	15.01
4	12.15	13.83
5	30.11	43.08
6	26.51	36.07
7	16.88	20.31
8	15.02	17.67
9	20.89	26.41
10	17.08	20.60
11	23.79	31.22
12	13.20	15.21
13	15.54	18.40
14	22.30	28.70
15	19.18	23.73
16	18.58	22.82
17	19.20	23.76
18	19.07	23.56

Appendix G

Raw data for the water activity (a_w) of different green kiwifruit-black currant fruit leather samples from central composite design experiments

Sample	Replicate 1	Replicate 2	Replicate 3	Mean a_w
1	0.59	0.58	0.58	0.59
2	0.58	0.56	0.55	0.56
3	0.45	0.44	0.44	0.45
4	0.43	0.41	0.41	0.41
5	0.77	0.77	0.75	0.76
6	0.74	0.74	0.73	0.74
7	0.58	0.55	0.56	0.56
8	0.47	0.45	0.45	0.46
9	0.54	0.53	0.52	0.59
10	0.60	0.59	0.59	0.53
11	0.64	0.63	0.63	0.63
12	0.45	0.45	0.45	0.45
13	0.47	0.46	0.45	0.46
14	0.63	0.63	0.61	0.63
15	0.53	0.51	0.51	0.52
16	0.52	0.51	0.51	0.51
17	0.53	0.52	0.51	0.52
18	0.52	0.52	0.52	0.52

Appendix H

Raw data for the L*a*b* colour values and chroma of different green kiwifruit-black currant fruit leather samples from central composite design experiments

Sample	Replicate	L*	a*	b*	Chroma
1	1	30.75	7.86	1.86	8.08
	2	30.99	7.63	1.74	7.83
	3	31.06	7.31	1.99	7.58
	4	30.87	7.83	2.17	8.13
	5	30.67	7.86	2.05	8.12
2	1	31.21	13.50	2.53	13.74
	2	30.61	10.59	1.87	10.75
	3	30.25	8.62	1.51	8.75
	4	30.41	9.28	1.64	9.42
	5	30.33	8.75	1.62	8.90
3	1	33.22	7.38	5.18	9.02
	2	31.65	7.32	4.95	8.84
	3	33.35	7.38	5.38	9.13
	4	32.32	7.62	4.52	8.86
	5	33.43	7.75	5.24	9.36
4	1	34.93	8.86	7.71	11.74
	2	34.50	8.43	7.41	11.22
	3	35.48	8.96	8.21	12.15
	4	34.51	8.94	7.48	11.66
	5	35.20	8.76	7.91	11.80
5	1	28.04	6.80	1.78	7.03
	2	26.76	7.18	1.84	7.41
	3	27.17	6.85	2.04	7.15
	4	28.36	6.00	1.24	6.13
	5	26.67	7.29	1.77	7.50
6	1	29.64	7.04	1.59	7.22
	2	29.41	6.55	1.26	6.67
	3	29.62	6.94	1.28	7.06
	4	29.73	7.25	1.62	7.43
	5	24.44	7.17	1.81	7.39

Raw data for the L*a*b* colour values and chroma of different green kiwifruit-black currant fruit leather samples from central composite design experiments

Sample	Replicate	L*	a*	b*	Chroma
7	1	30.99	7.23	3.60	8.08
	2	30.44	7.23	3.44	8.01
	3	31.42	7.19	3.68	8.08
	4	31.15	7.65	3.65	8.48
	5	31.51	7.83	3.82	8.71
8	1	34.25	8.61	6.62	10.86
	2	34.19	8.38	6.26	10.46
	3	34.47	8.52	6.56	10.75
	4	33.96	8.75	6.45	10.87
	5	33.89	8.63	6.11	10.57
9	1	30.76	7.42	2.14	7.72
	2	29.76	7.04	1.98	7.31
	3	30.16	7.46	2.19	7.77
	4	29.03	7.07	2.27	7.43
	5	30.64	7.13	1.99	7.40
10	1	32.02	7.94	3.90	8.85
	2	31.58	7.44	3.57	8.25
	3	31.46	7.25	3.22	7.93
	4	32.14	7.64	4.01	8.63
	5	31.98	7.02	3.24	7.73
11	1	30.08	7.63	1.97	7.88
	2	29.75	7.83	1.77	8.03
	3	30.90	7.83	1.94	8.07
	4	30.59	7.12	1.89	7.37
	5	30.40	7.23	2.00	7.50
12	1	34.51	8.83	7.85	11.81
	2	34.66	8.90	7.43	11.59
	3	36.26	8.71	8.35	12.07
	4	36.02	8.91	8.13	12.06
	5	35.86	9.00	8.21	12.18

Raw data for the L*a*b* colour values and chroma of different green kiwifruit-black currant fruit leather samples from central composite design experiments

Sample	Replicate	L*	a*	b*	Chroma
13	1	32.33	8.88	3.35	9.49
	2	31.70	8.39	3.32	9.02
	3	31.84	8.70	3.36	9.33
	4	31.86	8.99	3.56	9.67
	5	32.47	9.98	3.77	10.67
14	1	29.61	6.46	1.73	6.69
	2	30.00	6.86	2.12	7.18
	3	28.93	6.83	2.19	7.17
	4	30.34	6.72	2.32	7.11
	5	30.02	6.89	2.00	7.17
15	1	30.97	7.74	2.26	8.06
	2	31.69	7.57	2.49	7.97
	3	30.91	7.70	2.71	8.16
	4	30.74	7.24	2.26	7.58
	5	31.22	7.42	2.44	7.81
16	1	31.13	7.51	2.62	7.95
	2	31.19	7.50	2.62	7.94
	3	31.27	7.81	2.62	8.24
	4	31.17	7.53	2.20	7.84
	5	31.70	7.90	2.47	8.28
17	1	30.99	8.09	2.15	8.37
	2	30.31	8.04	1.76	8.23
	3	31.80	7.95	2.61	8.37
	4	31.37	7.70	2.09	7.98
	5	31.42	7.76	2.20	8.07
18	1	31.22	8.77	2.46	9.11
	2	30.77	7.57	1.99	7.83
	3	31.02	7.92	2.42	8.28
	4	30.92	7.89	2.19	8.19
	5	31.21	7.51	2.05	7.78

Appendix I

The mean results of puncturing force of different green kiwifruit-black currant fruit leather samples from central composite design experiments

Sample	Mean thickness (mm)	Mean puncturing force (kg)	Mean puncturing force (kg/mm)	Mean puncturing force (N/mm)
1	1.94	0.65	0.34	3.31
2	2.06	0.32	0.16	1.55
3	2.29	1.51	0.66	6.49
4	2.26	1.92	0.85	8.32
5	2.38	0.08	0.04	0.34
6	2.91	0.08	0.03	0.26
7	3.29	0.45	0.14	1.33
8	3.81	1.06	0.28	2.71
9	2.72	0.67	0.25	2.41
10	2.48	0.23	0.09	0.91
11	2.48	0.21	0.08	0.81
12	3.20	2.50	0.78	7.66
13	1.68	1.37	0.82	8.01
14	2.72	0.20	0.08	0.74
15	2.49	0.40	0.16	1.57
16	2.51	0.51	0.20	1.98
17	2.48	0.33	0.13	3.31
18	2.26	0.26	0.12	1.55

Appendix J

The mean ascorbic acid content of different green kiwifruit-black currant fruit leather samples from central composite design experiments

Sample	Mean volume of DPIP (ml)	Mean weight of sample (g)	Mean ascorbic acid content (mg/100 g DM)
1	4.43	0.61	109.20
2	4.22	0.61	103.56
3	2.12	0.61	50.33
4	2.08	0.61	48.90
5	7.21	0.61	207.83
6	6.50	0.61	178.36
7	3.73	0.61	91.22
8	3.08	0.61	73.89
9	5.75	0.61	146.73
10	4.04	0.61	98.97
11	6.30	0.61	166.80
12	2.48	0.61	58.59
13	3.45	0.61	83.05
14	5.53	0.61	143.83
15	5.46	0.61	136.46
16	4.84	0.61	120.34
17	5.65	0.61	141.22
18	5.27	0.61	131.67

Appendix K

ANOVA values for each of the responses of the Box-Behnken experiments

Source	Moisture content (quadratic)				Water activity (two-factor interaction)			
	Coefficient estimate	SE	F	P	Coefficient estimate	SE	F	P
Model	+23.26	0.34	22.19	0.001	+0.60	0.010	3.49	0.046
Sugar	+0.70	0.24	8.62	0.026	+0.038	0.014	7.29	0.024
Blackcurrant purée	-0.21	0.24	0.74	0.422	-0.011	0.014	0.66	0.439
Backcurrant purée	+2.88	0.24	145.04	< 0.0001	-0.026	0.014	3.57	0.091
Sugar* blackcurrant purée	+0.87	0.34	6.61	0.042	-0.060	0.020	9.33	0.014
Sugar* pectin	-0.77	0.34	5.11	0.065	-0.005	0.020	0.065	0.805
Blackcurrant purée* pectin	-0.44	0.34	1.71	0.239	+0.003	0.020	0.016	0.902
Sugar * sugar	+1.24	0.34	13.54	0.010				
Blackcurrant purée*blackcurrant purée	+0.55	0.34	2.62	0.157				
Pectin * pectin	-1.34	0.34	15.74	0.007				
Mean ± SD	23.48 ± 0.68				0.60 ± 0.039			

Source	L* (quadratic)				a* (quadratic)			
	Coefficient estimate	SE	F	P	Coefficient estimate	SE	F	P
Model	31.64	0.24	9.78	0.006	9.20	0.23	7.84	0.010
Sugar	0.076	0.17	0.19	0.675	-0.015	0.16	0.001	0.929
Blackcurrant purée	-1.26	0.17	53.06	0.000	-0.71	0.16	19.51	0.005
Blackcurrant purée	0.12	0.17	0.50	0.506	0.78	0.16	22.92	0.003
Sugar* blackcurrant purée	0.10	0.24	0.18	0.690	-0.080	0.23	0.12	0.739
Sugar* pectin	0.24	0.24	0.92	0.374	0.000	0.23	0.000	1.000
Blackcurrant purée* pectin	0.12	0.24	0.22	0.655	0.36	0.23	2.47	0.167
Sugar * sugar	0.30	0.24	1.53	0.263	0.23	0.23	1.02	0.351
Blackcurrant purée*blackcurrant purée	0.24	0.24	0.98	0.360	-0.73	0.23	10.27	0.019
Pectin * pectin	-1.35	0.24	30.40	0.002	-0.86	0.23	14.24	0.009
Mean ± SD	31.23 ± 0.49				8.51 ± 0.46			

ANOVA values for each of the responses of the Box-Behnken experiments (continued)

Source	b* (quadratic)				Chroma (quadratic)			
	Coefficient estimate	SE	F	P	Coefficient estimate	SE	F	P
Model	3.00	0.14	48.78	< 0.0001	9.67	0.28	9.97	0.006
Sugar	-0.27	0.10	7.22	0.036	-0.13	0.20	0.42	0.541
Blackcurrant purée	-1.76	0.10	306.68	< 0.0001	-1.34	0.20	45.47	0.001
Blackcurrant purée	0.51	0.10	25.75	0.002	0.90	0.20	20.25	0.004
Sugar* blackcurrant purée	0.0075	0.14	0.0027	0.960	-0.032	0.28	0.013	0.912
Sugar* pectin	0.0025	0.14	0.0003	0.987	-0.01	0.28	0.0013	0.973
Blackcurrant purée* pectin	0.097	0.14	0.47	0.518	0.34	0.28	1.42	0.279
Sugar * sugar	0.64	0.14	20.28	0.004	0.51	0.28	3.26	0.121
Blackcurrant purée*blackcurrant purée	0.80	0.14	32.08	0.001	-0.26	0.28	0.87	0.387
Pectin * pectin	-0.97	0.14	46.58	0.001	-1.20	0.28	18.05	0.005
Mean ± SD	3.24 ± 0.28				9.20 ± 0.56			

Source	Puncturing force (linear)				Ascorbic acid content (linear)			
	Coefficient estimate	SE	F	P	Coefficient estimate	SE	F	P
Model	4.96	0.40	12.49	0.001	134.12	3.93	13.63	0.000
Sugar	-2.16	0.57	14.32	0.003	-25.04	5.56	20.27	0.001
Blackcurrant purée	-0.10	0.57	0.032	0.862	2.29	5.56	0.17	0.688
Pectin	2.74	0.57	23.13	0.000	-25.16	5.56	20.46	0.001
Mean ± SD	4.96 ± 1.61				134.12 ± 15.73			

Appendix L

ANOVA for the central composite design responses

Source	Moisture content (two-factor interaction)				Water activity (quadratic)			
	Coefficient estimate	SE	F	P	Coefficient estimate	SE	F	P
Model	23.50	0.22	180.09	< 0.0001	0.53	0.007	60.71	< 0.0001
Sugar	-1.74	0.30	34.31	0.000	-0.025	0.005	22.08	0.002
Blackcurrant purée	-7.10	0.30	572.83	< 0.0001	-0.095	0.005	318.88	< 0.0001
Blackcurrant purée	5.60	0.30	356.15	< 0.0001	0.068	0.005	163.38	< 0.0001
Sugar* blackcurrant purée	0.49	0.33	2.18	0.168	-0.011	0.006	3.58	0.095
Sugar* pectin	-0.97	0.33	8.52	0.014	-0.006	0.006	1.10	0.324
Blackcurrant purée* pectin	-3.42	0.33	106.57	< 0.0001	-0.024	0.006	15.94	0.004
Sugar * Sugar					0.026	0.010	6.39	0.035
Blackcurrant purée*blackcurrant purée					0.006	0.010	0.33	0.584
Pectin * pectin					0.011	0.010	1.12	0.320
Mean ± SD	23.50 ± 0.94				0.55 ± 0.017			

Source	L* (quadratic)				a* (two-factor interaction)			
	Coefficient estimate	SE	F	P	Coefficient estimate	SE	F	P
Model	31.37	0.16	48.52	< 0.0001	7.88	0.23	5.81	0.006
Sugar	0.78	0.13	38.84	0.000	0.53	0.16	9.82	0.010
Blackcurrant purée	2.07	0.13	272.34	< 0.0001	0.20	0.16	1.35	0.269
Blackcurrant purée	-1.02	0.13	65.99	< 0.0001	-0.66	0.16	14.94	0.003
Sugar* blackcurrant purée	0.54	0.14	14.86	0.005	-0.021	0.23	0.013	0.913
Sugar* pectin	0.30	0.14	4.58	0.065	-0.30	0.23	2.57	0.137
Blackcurrant purée* pectin	0.38	0.14	7.16	0.028	0.47	0.23	6.19	0.030
Sugar * Sugar	-0.64	0.24	7.10	0.029				
Blackcurrant purée*blackcurrant purée	1.30	0.24	29.33	0.001				
Pectin * pectin	-0.69	0.24	8.13	0.021				
Mean ± SD	31.36 ± 0.40				7.88 ± 0.54			

Source	b* (quadratic)				Chroma (quadratic)			
	Coefficient estimate	SE	F	P	Coefficient estimate	SE	F	P
Model	2.74	0.27	15.91	0.000	8.27	0.28	7.74	0.004
Sugar	0.66	0.22	8.98	0.017	0.83	0.23	13.57	0.006
Blackcurrant purée	2.19	0.22	99.30	< 0.0001	1.14	0.23	25.63	0.001
Blackcurrant purée	-0.47	0.22	4.58	0.065	-0.84	0.23	13.93	0.006
Sugar* blackcurrant purée	0.73	0.25	8.72	0.018	0.33	0.25	1.70	0.228
Sugar* pectin	-0.0025	0.25	0.0001	0.992	-0.31	0.25	1.53	0.251
Blackcurrant purée* pectin	-0.27	0.25	1.25	0.295	0.29	0.25	1.27	0.292
Sugar * sugar	-0.31	0.42	0.54	0.484	-0.53	0.43	1.51	0.254
Blackcurrant purée*blackcurrant purée	1.79	0.42	18.02	0.003	1.42	0.43	10.63	0.011
Pectin * pectin	-0.39	0.42	0.85	0.383	-0.089	0.43	0.042	0.843
Mean ± SD	3.35 ± 0.69				8.71 ± 0.72			

Source	Puncturing force (linear)				Ascorbic acid content (linear)			
	Coefficient estimate	SE	F	P	Coefficient estimate	SE	F	P
Model	2.96	0.38	11.71	0.000	116.16	4.16	31.68	< 0.0001
Sugar	-0.013	0.51	0.007	0.980	-10.16	5.59	3.31	0.090
Blackcurrant purée	2.02	0.51	15.87	0.001	-44.28	5.59	62.86	< 0.0001
Pectin	-2.23	0.51	19.27	0.001	30.01	5.59	28.87	< 0.0001
Mean	2.96 ±1.61				116.16 ±17.66			

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